The manufacture of pulp and paper

Joint Textbook Committee of the Paper Industry, ...

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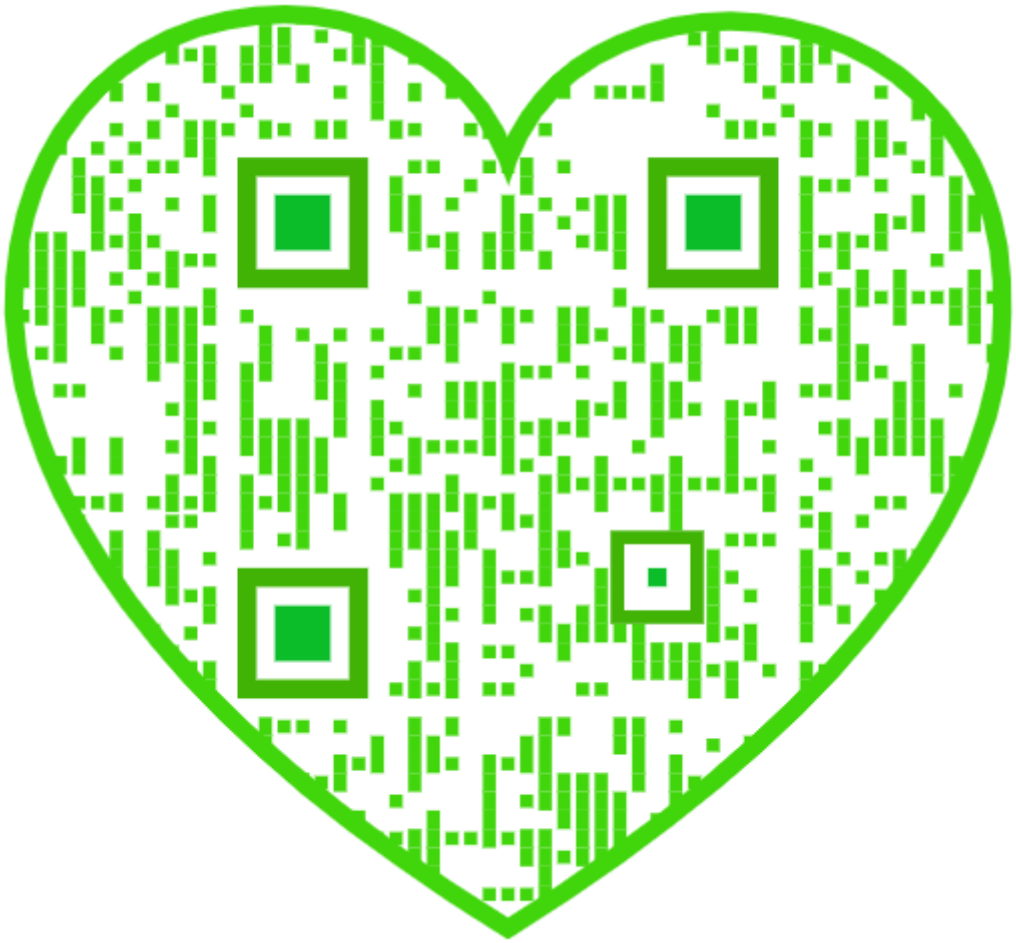

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THE MANUFACTURE
OF
PULP AND PAPER

VOLUME III

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Pulp and Paper Manufacture

IN FIVE VOLUMES

An Official Work Prepared
under the direction of the

Joint Executive Committee of the
Vocational Education Committees of the
Pulp and Paper Industry of the
United States and Canada

VOL. I—MATHEMATICS, HOW TO READ DRAWINGS, PHYSICS.

II—MECHANICS AND HYDRAULICS, ELECTRICITY, CHEMISTRY.

III—PREPARATION OF PULP.

IV, V—MANUFACTURE OF PAPER.

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THE MANUFACTURE OF PULP AND PAPER

A TEXTBOOK OF MODERN PULP AND PAPER MILL PRACTICE

Prepared Under the Direction of the Joint Executive Committee on Vocational Education Representing the Pulp and Paper Industry of the United States and Canada

VOLUME III

PROPERTIES OF PULPWOOD; PREPARATION OF WOOD; MANUFACTURE OF MECHANICAL, SULPHITE, SODA, AND SULPHATE PULPS; TREATMENT OF PULP; REFINING AND TESTING OF PULP; BLEACHING OF PULP

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PREFACE

In numerous communities where night schools and extension classes have been started or planned, or where men wished to study privately, there has been difficulty in finding suitable textbooks. No books were available in English, which brought together the fundamental subjects of mathematics and elementary science and the principles and practice of pulp and paper manufacture. Books that treated of the processes employed in this industry were too technical, too general, out of date, or so descriptive of European machinery and practice as to be unsuitable for use on this Continent. Furthermore, a textbook was required that would supply the need of the man who must study at home because he could not or would not attend classes.

Successful men are constantly studying; and it is only by studying that they continue to be successful. There are many men, from acid maker and reel-boy to superintendent and manager, who want to learn more about the industry that gives them a livelihood and by study to fit themselves for promotion and increased earning power. Pulp and paper makers want to understand the work they are doing—the how and why of all the various processes. Most operations in this industry are, to some degree, technical, being essentially either mechanical or chemical. It is necessary, therefore, that the person who aspires to understand these processes should obtain a knowledge of the underlying laws of Nature through the study of the elementary sciences and mathematics, and be trained to reason clearly and logically.

After considerable study of the situation by the Committee on Education for the Technical Section of the Canadian Pulp and Paper Association and the Committee on Vocational Education for the Technical Association of the (U. S.) Pulp and Paper Industry, a joint meeting of these committees was held in Buffalo

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in September, 1918, and a Joint Executive Committee was appointed to proceed with plans for the preparation of the text, its publication, and the distribution of the books. The scope of the work was defined at this meeting, when it was decided to provide for preliminary instruction in fundamental Mathematics and Elementary Science, as well as in the manufacturing operations involved in modern pulp and paper mill practice.

The Joint Executive Committee then chose an Editor, Associate Editor, and Editorial Advisor, and directed the Editor to organize a staff of authors consisting of the best available men in their special lines, each to contribute a section dealing with his specialty. A general outline, with an estimated budget, was presented at the annual meetings in January and February, 1919, of the Canadian Pulp and Paper Association, the Technical Association of the Pulp and Paper Industry and the American Paper and Pulp Association. It received the unanimous approval and hearty support of all, and the budget asked was raised by an appropriation of the Canadian Pulp and Paper Association and contributions from paper and pulp manufacturers and allied industries in the United States, through the efforts of the Technical Association of the Pulp and Paper Industry.

To prepare and publish such a work is a large undertaking; its successful accomplishment is unique, as evidenced by these volumes, in that it represents the cooperative effort of the Pulp and Paper Industry of a whole Continent.

The work is conveniently divided into sections and bound into volumes for reference purposes; it is also available in pamphlet form for the benefit of students who wish to master one part at a time, and for convenience in the class room. This latter arrangement makes it very easy to select special courses of study; for instance, the man who is specially interested, say, in the manufacture of pulp or in the coloring of paper or in any other special feature of the industry, can select and study the special pamphlets bearing on those subjects and need not study others not relating particularly to the subject in which he is interested, unless he so desires. The scope of the work enables the man with but little education to study in the most efficient manner the preliminary subjects that are necessary to a thorough understanding of the principles involved in the manufacturing processes and operations; these subjects also afford an excellent review and reference textbook to others. The work

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is thus especially adapted to the class room, to home study, and for use as a reference book.

It is expected that universities and other educational agencies will institute correspondence and class room instruction in Pulp and Paper Technology and Practice with the aid of these volumes. The aim of the Committee is to bring an adequate opportunity for education in his vocation within the reach of every one in the industry. To have a vocational education means to be familiar with the past accomplishments of one's trade and to be able to pass on present experience for the benefit of those who will follow.

To obtain the best results, the text must be diligently studied; a few hours of earnest application each week will be well repaid through increased earning power and added interest in the daily work of the mill. To understand a process fully, as in making acid or sizing paper, is like having a light turned on when one has been working in the dark. As a help to the student, many practical examples for practice and study and review questions have been incorporated in the text; these should be conscientiously answered.

This is the first volume published in English that deals solely and comprehensively with the manufacture of wood pulp. The attention here given to this subject is warranted by the essential place now held by this source of paper-making material. From a practically unknown factor fifty years ago, the making of paper is now a major industry, employing thousands of workmen, and converting much wood, otherwise worthless, into an important article of international commerce. The greatest advances in connection with the paper industry have been in the development of pulp manufacture. Even this volume is too small to tell the whole story, the study of which will fascinate and benefit anyone connected with this industry.

A feature of this series of volumes is the wealth of illustrations, which are accompanied by detailed descriptions of typical apparatus. In order to bring out a basic principle, it has been necessary, in some cases, slightly to alter the maker's drawing, and exact scales have not been adhered to. Since the textbook is in no sense a "machinery catalog," maker's names have been mentioned only when they form a necessary descriptive item. Much of the apparatus illustrated and many of the processes

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described are covered by patents, and warning is hereby given that patent infringements are costly and troublesome.

A valuable feature of this work, which distinguishes it from all others in this field, is that each Section was examined and criticised while in manuscript by several competent authorities; in fact, this textbook is really the work of more than one hundred men who are prominent in the pulp and paper industry. Without their generous assistance, often at personal sacrifice, the work could not have been accomplished. Even as it stands, there are, no doubt, features that still could be improved. The Committee, therefore, welcomes helpful criticisms and suggestions that will assist in making future editions of still greater service to all who are interested in the pulp and paper industry.

The Editor extends his sincere thanks to the Committee and others, who have been a constant support and a source of inspiration and encouragement; he desires especially to mention Mr. George Carruthers, Chairman, and Mr. R. S. Kellogg, Secretary, of the Joint Executive Committee; Mr. J. J. Clark, Associate Editor, Mr. T. J. Foster, Editorial Advisor, and Mr. John Erhardt of the McGraw-Hill Book Company, Inc.

The Committee and the Editor have been generously assisted on every hand; busy men have written and reviewed manuscript, and equipment firms have contributed drawings of great value and have freely given helpful service and advice. Among these kind and generous friends of the enterprise are: Mr. M. J. Argy, Mr. O. Bache-Wiig, Mr. James Beveridge, Mr. J. Brooks Beveridge, Mr. H. P. Carruth, Mr. Martin L. Griffin, Mr. H. R. Harrigan, Mr. Kenneth T. King, Mr. Maurice Neilson, Mr. Elis Olsson, Mr. J. S. Riddile, Mr. George K. Spence, Mr. Edwin Sutermeister, Mr. F. G. Wheeler, and Bird Machine Co., Canadian Ingersoll-Rand Co., Claflin Engineering Co., Dominion Engineering Works, E. I. Dupont de Nemours Co., General Electric Co., Harland Engineering Co., F. C. Huyck & Sons, Hydraulic Machinery Co., Improved Paper Machinery Co., E. D. Jones & Sons Co., A. D. Little, Inc., E. Lungwitz, National Aniline and Chemical Works, Paper Makers Chemical Co., Process Engineers, Pusey & Jones Co., Rice, Barton & Fales Machine and Iron Works, Ticonderoga Paper Co., Waterous Engine Works Co., Westinghouse Electric & Manufacturing Co., and many others, particularly the authors of the various

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sections, who have devoted so much time and energy to the preparation of manuscript, often at personal sacrifice.

J. NEWELL STEPHENSON,
Editor

FOR THE

JOINT EXECUTIVE COMMITTEE ON VOCATIONAL EDUCATION,
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SECTION 1

PROPERTIES OF PULP WOOD

(PART 1)

BY H. N. LEE, A. M.

STRUCTURAL, MICROSCOPICAL, AND PHYSICAL PROPERTIES OF WOOD

IMPORTANT FIBER PRODUCING PLANTS OTHER THAN WOOD

1. Classification of Plants Used in Pulp and Paper Industry.—The fiber of many different kinds of plants can be made into pulp and paper. The principal factors that determine whether a plant shall or shall not be used in the manufacture of paper are: suitability of fiber; dependability of supply; cost of collection, transportation, and preparation; deterioration in storage.

At the present time, wood is by far the plant most used; and the **coniferous** trees are utilized to a much greater extent than the trees of the **hardwood,** or **broad-leaved,** group; though for reasons of forest economy, it is necessary to make use of the latter also. In general, all plants utilized in pulp and paper manufacture may be divided into six (6) classes, as shown in Table I, which has been arranged according to F. C. Clark, in *Paper*, Vol. XXIII, Feb. 20, 1919.

2. Use of Plants Other than Wood.—*Cotton*, *linen*, and *bombax wool* reach the pulp mill in the form of rags or waste from other manufactures. *Jute*, *hemp sisal hemp*, and *manila hemp* usually

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TABLE I

CLASSIFICATION OF FIBERS USED IN PAPERMAKING

(A) Seed-hair fiber	Cotton (*Gossypium*) Bombax wool (*Bombacaceæ*)
(B) Stem fiber (Bast family)	Flax (linen) *Linum usitatissimum*) Hemp (*Cannabis sativa*) Jute or Calcutta hemp (*Corchorus capsularis & olitorius*) Nettle fibers: Common nettle (*Urtica dioica*); China grass (*Boehmeria nivea*); Ramie (*Boehmeria tenacissima*) Indian corn (*Zea mais*) Sugar cane (*Saccharum officinarum*) Bamboo (*Bambusa sp.*) Sunn hemp (*Crotalaria juncea*) Manila hemp (*Musa textilis*) Straw (from various cereals) Esparto (*Lygeum spartum*)
(C) Leaf fiber	New Zealand hemp (*Phormium tenax*) Manila hemp (*Musa textilis*) Sisal or Domingo hemp (*Agave rigida*) Aloe fiber (*Fourcroya fœtida*) Pineapple leaf fiber (*Ananas sativa*) Vegetable wool from green cones of pine and fir Palm (*Palmæ*)
(D) Fruit fiber	Cocoanut fiber (*Cocos nucifera*)
(E) Wood fiber	Resinous or coniferous: Larch, tamarack (*Larix*); Fir (balsam and others) (*Abies*); Spruce (*Picea*); Cedar (*Chamæcyparis, Juniperus, Cupressus, Thuja*); Pine (*Pinus*); Hemlock (*Tsuga*); Cypress (*Taxodium*); Douglas fir (*Pseudotsuga*); etc. Non-resinous or broad-leaf: Birch (*Betula*); Beech (*Fagus*); Maple (*Acer*); Poplar (*Populus*); Chestnut (*Castanea*); Gum (*Nyssa*); Basswood (*Tilia*); Tulip (*Liriodendron*); etc.

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come from cordage or rough textile waste. *Esparto* is a grass that grows in Spain and Northern Africa; it is cut especially for pulp making. All the foregoing are discussed in detail the Section on *Preparation of Rags and Other Fibers* in Vol. IV. With the exception of wood and the plants just mentioned, the fibers of the other plants listed in Table I are used only to a very slight extent or are not used at all at the present time. Although some of these plants yield an inferior pulp, the main reason why they are not utilized to a greater extent is because they yield such a *small percentage* of pulp.

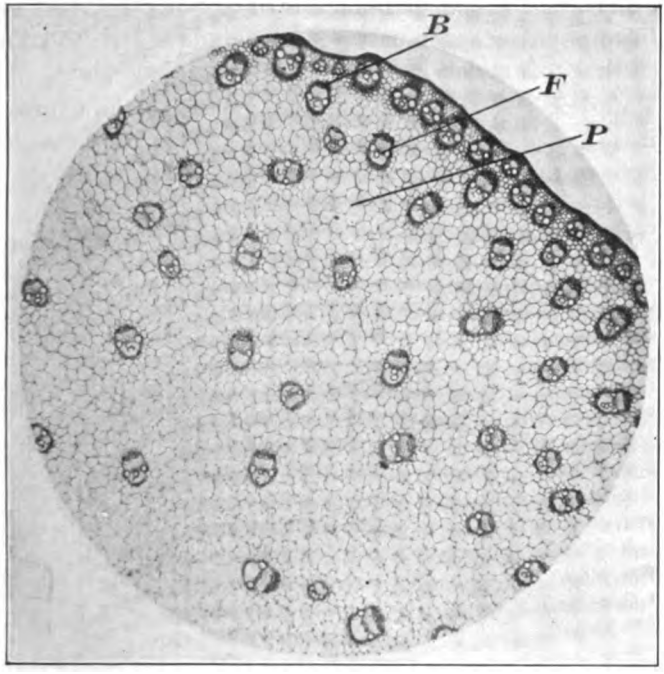

FIG. 1.—Cross Section of Part of Indian Corn Stem. × 20.
(Prepared by the Forest Products Laboratories of Canada.)
In this and similar plants, the only parts of value for paper pulp are the bast fibers *B*, which show as the darkest parts of the bundles *F*. The thin-walled parenchyma, or pith cells *P*, which make up the most of the stem, are of little or no value.

3. Structure of Stem of Indian Corn.—In Fig. 1[1] is shown a cross section of the stem of Indian corn, from which may be estimated the relative amount of useful fiber and useless or

[1] Figs. 1–3, 5–8, 11–13, and 16–22, inclusive, are reproductions of very excellent photomicrographs prepared by the Forest Products Laboratories of Canada, to whom special thanks are extended; we particularly wish to thank Mr. J. D. Hale, of the Forest Products Laboratories of Canada.

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waste material; this figure may be used for the same purpose in connection with manila, New Zealand, and sisal hemps, bamboo, straw, sugar cane, palm, pineapple leaf, and similar plants.

The only valuable parts of such plants are those that appear as dark spots in the illustration. These are called **fibro-vascular** bundles *F*, because they are made up of bundles of fibers, including chiefly the so-called **bast-fibers** *B*. The space between the bundles is filled with short pith cells *P*. Whether it is the stem or the leaf of these plants that is used, there are always a very large number of short, thin-walled cells (fibers) which are practically valueless for the manufacture of paper pulp; this useless part fills up all the space between the bundles, and it can easily be seen that this makes up the greater part of the plant.

4. Reference Letters in Illustrations.—In all the figures used to illustrate Part 1 of this Section, the same reference letters always have the same meaning, as in the following list:

List of Reference Letters Used in Marking Illustrations

A, annual ring
B, bast fibers
BP, bordered pit
C, cross section
Cm, cambium
CRC, central ray cell
D, resin duct or canal
F, fibro-vascular bundle
H, heartwood
K, bark
L, middle lamella
M, medullary ray
MRC, marginal ray cell
P, parenchyma
P, pith
R, radial section
S, sapwood
Sm, summerwood
Sp, springwood
SP, simple pit
T, tangential section
Tr, tracheid
V, vessel or pore
W, wood
WF, wood fiber

5. Structure of Stem of Clematis.—A cross section of the stem of **clematis** is shown in Fig. 2; this is typical of the general make-up of common plants that die at the end of each year. As can be seen, the fiber bundles are arranged in a single circle in the outer part of the stem. The part fitting like a cap over each bundle is the group of bast fibers, while the rest of the bundle includes short, more or less woody fibers. The hollow center of the stem is surrounded by pith cells, which, like those of Indian corn, are very short and thin. Here, again, only the bast fibers are useful for paper pulp, and the proportion of these is so small

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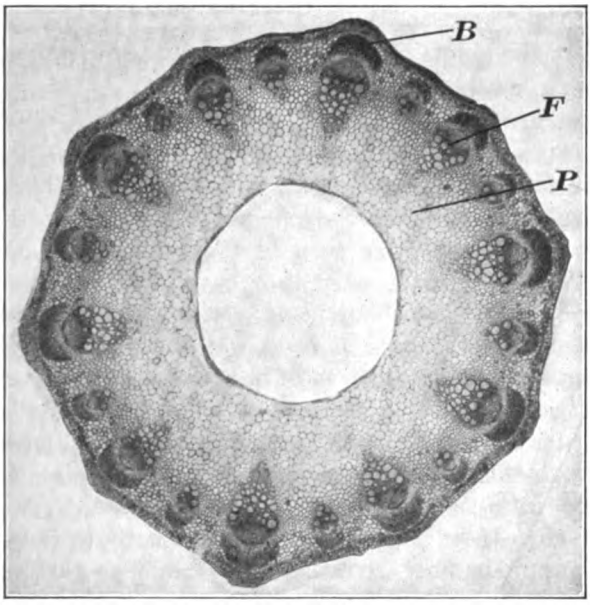

FIG. 2.—Cross Section of Clematis Stem. × 20.
(Prepared by the Forest Products Laboratories of Canada.)
In this and similar plants, the only parts of value for paper pulp are the bast fibers *B*, which show as caps fitting on each fibro-vascular bundle *F*. The parenchyma (pith) cells *P* and the cells of the bundles, with the exception of the bast cells, are of little or no value.

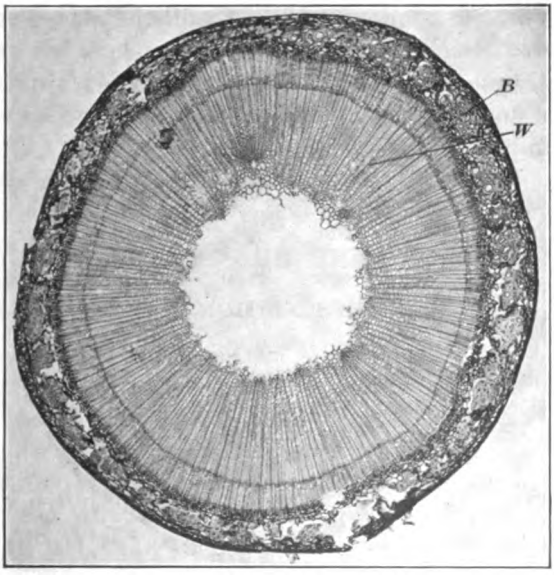

FIG. 3.—Cross Section of Stem of Flax Straw. × 20.
(Prepared by the Forest Products Laboratories of Canada.)
The bast fibers *B*, which form an almost complete ring just inside the periphery of the stem, are the fibers used in paper making. Inside this is the wide, woody part *W* of the stem, while the center is hollow. The wood is made up of very short fibers, and is of little or no value in pulp making.

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as to make the plants of practically no value in the manufacture of pulp.

6. Structure of Stem of Flax.—Fig. 3 shows the appearance of the cross section of the stem of **flax** (*Linum usitatissimum*); it also illustrates in a general way the structure of *hemp*, *jute*, *cotton* (stalk), and other woody plants. In this class of plants, the individual bundles as seen in the clematis do not show, because they are so large that they have grown together. The whole central part is hollow; and, outside of this, these stem are made up of a wide zone of wood, which is practically the same as the wood of trees. But the fibers are very short, and they are of little or no value for pulp manufacture. The valuable part of such stems is in what is ordinarily called the *bark*, for it is here that the bast fibers occur, as shown at *B*. Since the bast fibers form so small a part of the stem, and since the rest is of no value, these plants are not used directly as pulp-making materials; but the fiber from them is obtained as waste from the cordage or textile industries.

7. Trees.—The trees are by far the most important of the plants used in the production of paper pulp. As shown in the classification, Table I, trees are divided into two main groups: the **resinous,** or **coniferous,** trees and the **non-resinous,** or **broad-leaved,** trees. After discussing wood in general, *spruce* will be taken as an example of resinous woods and *poplar* as an example of non-resinous woods, and both types will be described in considerable detail.

STRUCTURE AND GROWTH OF WOOD

GENERAL DESCRIPTION OF WOOD

8. Wood Fibers.—Wood is not a solid, homogeneous substance like steel or glass, but is made up of innumerable little hollow tubes, called **fibers,** which are usually closed at their ends. In any particular wood, the greater proportion of the fibers are very similar to one another, but there are some that are different; and in comparing one wood with another, very different kinds of fibers will be found. The fact that fibers differ not only in size and shape but also in actual structure and arrangement, is really the explanation of why one kind of wood

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differs from another. In general, it may be said that the greater the difference in general appearance between two kinds of woods the greater will be the difference in the shape and arrangement of the individual elements of which the respective woods are composed. No two species of wood are exactly alike in structure; hence, it is possible to determine what kind or species any piece of wood is if one knows the structure of the various kinds. Tables II, III, IV, and V give the characteristics, by means of which, it is possible to distinguish the woods used in making paper pulp. Most of the fibers are arranged lengthwise, or along the grain, in a piece of wood (these would be in a vertical position in a standing tree trunk), and each fiber is firmly cemented to all the fibers adjacent to and surrounding it. A certain number of the fibers, or rather cells, of the wood lie in groups, which extend from the center of the tree outward; that is, they occupy the same position that would be occupied by a nail that is driven from the surface to the center of the tree. In addition to the fibers placed vertically and the groups of cells lying horizontally in the standing tree, there are certain other cells, which occur in most woods, and which are often characteristic in shape or distribution of each different kind of wood; these will be described in detail in the case of some of the important pulp woods.

9. How a Tree Grows.—Before considering the minute structure of wood, a description will be given of how a tree grows. The actual growth takes place in the following manner. The roots absorb water, which contains a certain amount of mineral matter; this water, called the **sap,** is drawn up through the trunk of the tree, through the sapwood, which lies between the heartwood and the bark. The sap passes through the branches and, finally, to the green leaves. In the leaves, the sap is combined with carbon dioxide gas CO_2, which is taken into the leaves from the air, and the final product of the chemical reaction is sugar. This sugar is carried, in solution, down through the inner bark of the tree, and from thence into the wood, through what are called *medullary rays M*, (see Fig. 4). For explanation of reference letters, see Art. **4**. For definition of terms, see *Glossary*, Art. **24.**

At the part of the tree where the bark is attached to the wood, there is a special layer of cells, called the **cambium cells,** *Cm*, which take up this sugar solution and grow and divide, making

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more and more cells. The new cells on the wood side gradually develop into *wood fibers* and the other types of woody cells, while those on the bark side form *bark fibers;* thus it is that a new layer

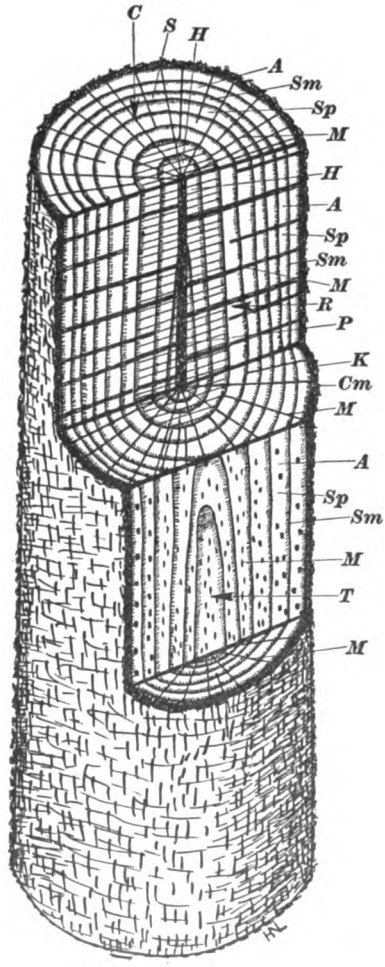

FIG. 4.—Diagram of a Log of Wood, Cut to Show Cross, Radial, and Tangential Sections.

C, cross section; *R*, radial section; *T*, tangential section; *S*, sapwood; *H*, heartwood; *A*, annual ring; *Sm*, summerwood; *Sp*, springwood; *M*, medullary ray; *P*, pith: *K*, bark; *Cm*, cambium.

of wood cells, or fibers, are added to the surface of the wood each year. Each year's **growth ring,** or **annual ring,** *A*, is divided into two parts: that which is formed in the early part of the

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growing season, which is composed of fibers with thin walls that enclose a comparatively large space *Sp*; and that which is formed during the later part of the growing season, which is made up of fibers having thicker walls that enclose a smaller space *Sm*. It is because of this difference between the two parts of the annual growth that the annual rings can be distinguished in wood, the early growth of each year being lighter in color, less dense, and softer than that formed later. Each year, one light, soft ring *Sp*, the so-called *early* wood or **springwood,** and one denser, harder ring *Sm*, the so-called *late* wood or **summerwood,** are added as long as the tree lives and grows. By counting the darker rings, one of which is formed each year, the age of the tree may be accurately determined.

The annual rings vary greatly in width; those which are formed in seasons very favorable for tree growth may be one-half an inch or more wide, while those formed in seasons unfavorable for tree growth may be less than one-fiftieth of an inch in width. In a tree grown in the forest, the annual rings of the first years of the tree's growth are usually the widest and those of the last years the narrowest. In spruce, the rings average from one-eighth to one-sixteenth of an inch in width.

10. As the tree grows larger, the inner (central) part of the tree trunk *H*, called the **heartwood,** becomes more or less closed up. In many kinds of wood, the heartwood is darker in color than the part *S* outside of it, called the sapwood. It is only in the outer part, the **sapwood,** that water, or sap, can pass through the trunk in its journey from the roots to the leaves. In some woods, like spruce, balsam fir, and poplar, the heartwood and sapwood are, unless decayed, of the same color; but in most woods, like pine and oak, the heartwood is much darker in color than the sapwood. The heartwood and sapwood, even when different in color, are not different in structure; for the fibers formed during any growing season do not materially change in size or structure during later seasons. There is a slight change in the chemical nature of the wood, chiefly due to the resins, tannins, and other substances contained in the fibers, but there is very little change in the actual chemical composition of the cell walls. In many woods, small, foam-like growths also develop in the inner sapwood and heartwood, which fill up the open spaces in certain cells and thus prevent the passage of sap.

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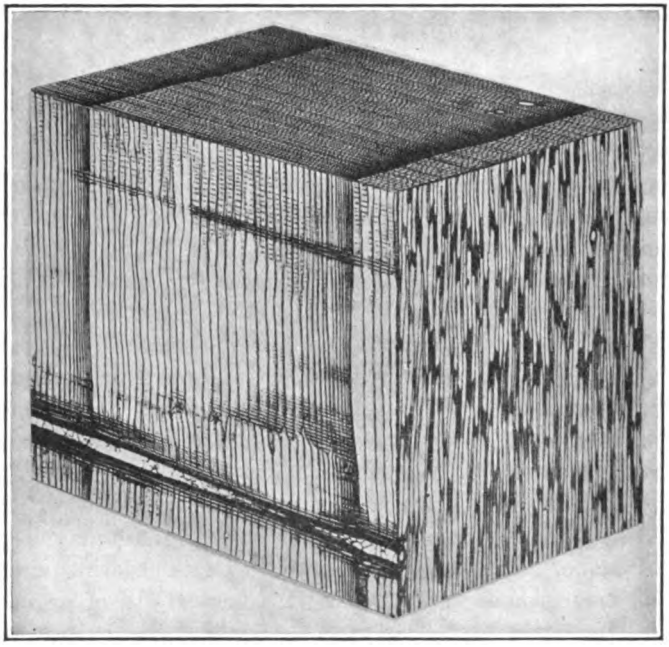

FIG. 5.—Photomicrograph of a Block of Spruce Wood. × 20.
(Prepared by the Forest Products Laboratories of Canada.)

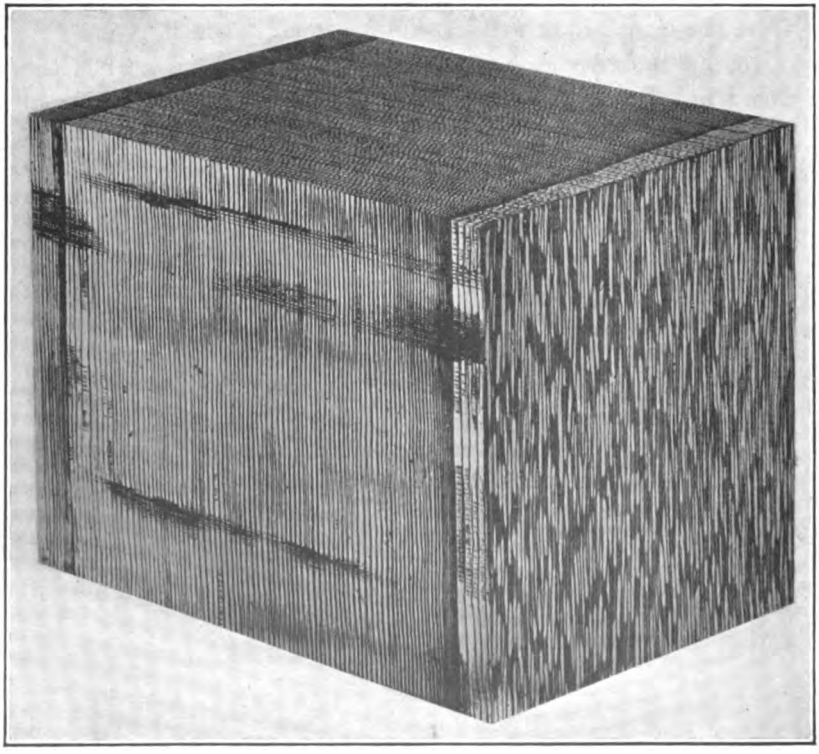

FIG. 6.—Photomicrograph of a Block of Balsam Fir Wood. × 20.
(Prepared by the Forest Products Laboratories of Canada.)

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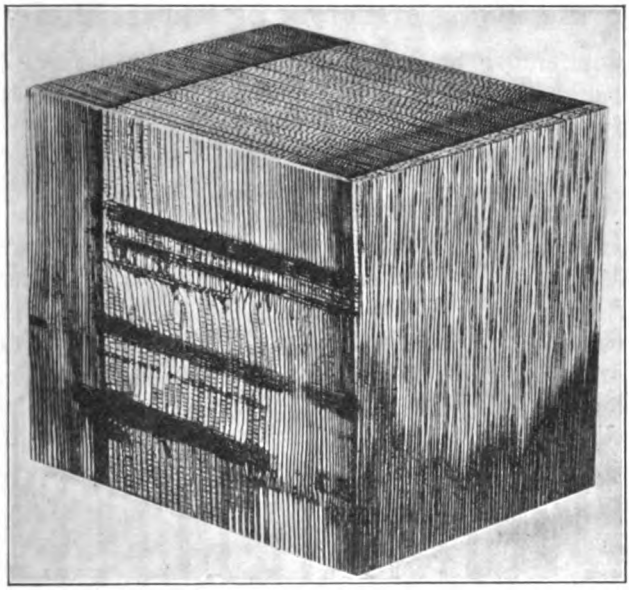

FIG. 7.—Photomicrograph of a Block of Hemlock Wood. × 20.
(Prepared by the Forest Products Laboratories of Canada.)

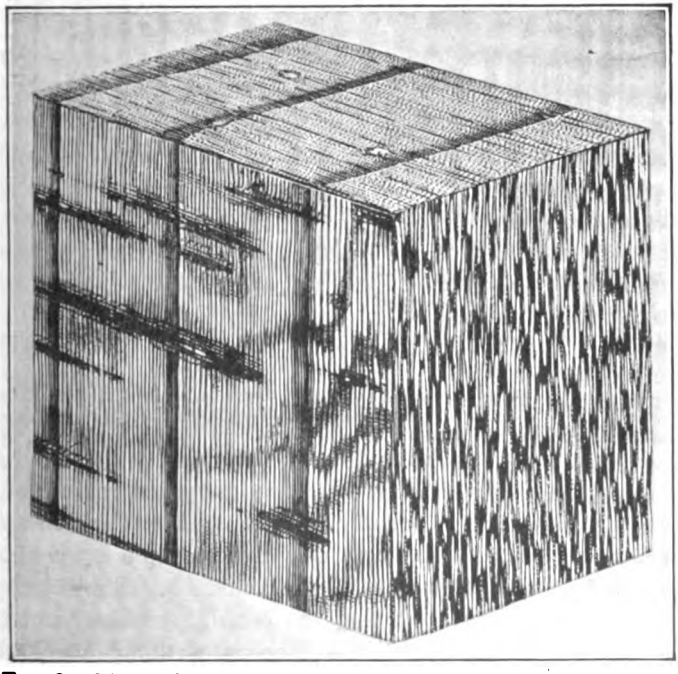

FIG. 8.—Photomicrograph of a Block of Jack Pine Wood. × 20.
(Prepared by the Forest Products Laboratories of Canada.)

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THE MINUTE STRUCTURE OF SPRUCE WOOD

11. Coniferous, or Resinous, Woods.—As before stated, spruce will here be taken as an example of coniferous, or resinous, woods; its structure will now be examined minutely.

Fig. 9 is a diagram of a small block of spruce wood, very much enlarged, showing a part of one annual ring.

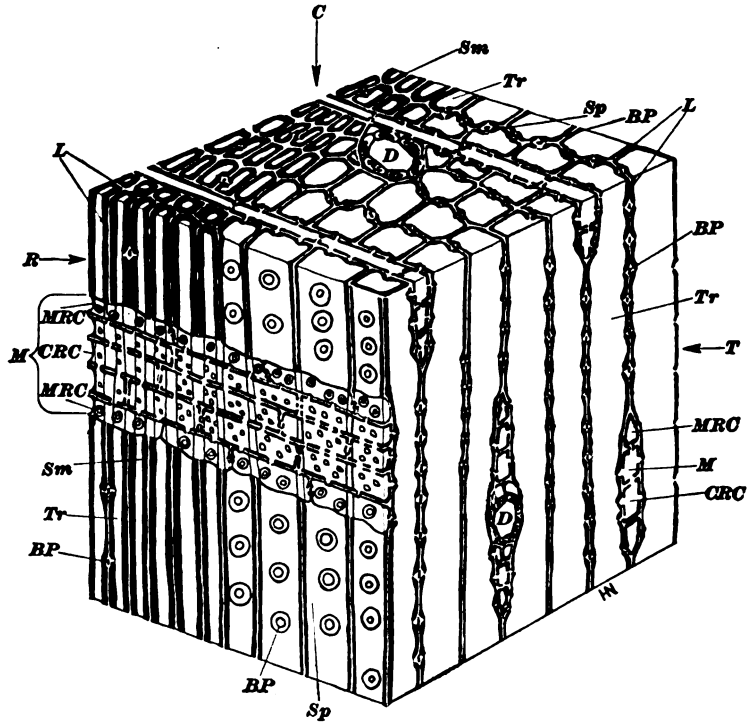

FIG. 9.—Diagram of a Small Block of Spruce Wood, Greatly Enlarged, Showing a Part of One Annual Ring.

C, cross section; *R*, radial section; *T*, tangential section; *D*, resin duct; *Sm*, summerwood; *Sp*, springwood; *Tr*, tracheid; *BP*, bordered pit; *L*, middle lamella; *M*, medullary ray; *CRC*, central ray cell; *MRC*, marginal ray cell.

As may be seen in the illustration, most of the fibers, or **tracheids** *Tr*, as they are technically called, extend lengthwise in the wood; they are cemented to one another by a layer of substance that is called the **middle lamella** *L*. This layer, the middle lamella, dissolves during the cooking process, and thus allows the fibers (tracheids) to separate. The larger, thin-

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walled tracheids are those of the springwood *Sp*, while the thick-walled tracheids are those of the summerwood *Sm*. The groups of cells *M*, which extend crosswise (outward from the center of the trunk), are the **medullary ray cells,** frequently called, simply, the **ray cells.** Each group is called a **ray**; and it may be noted that the cells *MRC* on the margins of the ray look different from those in the center *CRC*. This is because of the difference in the openings that occur in the cell walls, the openings in the cells of the margins showing a double circle, or *bordered pit*, while those of the central cells show only a single circle, or *simple pit*. The ray cells, because they are so short, are of little value for pulp; fortunately, however, they form less than ten per cent of the total volume of the wood, while the long fibers, or tracheids, which are of just the right dimensions for pulp, make up the remaining ninety per cent.

12. Resin Ducts.—Near the center of the top surface of the block, Fig. 9, which shows the cross section *C* of the wood, is an open space *D*, which is surrounded by cells that are smaller and thinner walled than the tracheids; this open space is a **resin duct, or canal,** and the cells surrounding it can form and secrete resin. An open space *D* may also be seen in the ray, near the center of the front face of the block; this is a resin duct in the ray. These open spaces, or resin ducts, extend lengthwise and cross wise throughout all the wood of spruce trees; it is from these ducts that the **resin, or pitch,** comes, which is so often seen on the ends of logs. A certain amount of resin also occurs in all the central cells of the rays; hence, some pitch is present in coniferous woods, like balsam fir, which do not have resin ducts in the wood. On the surfaces of some of the tracheids (fibers) may be seen double circles *BP*; these show the openings called **bordered pits,** which allow the sap to pass from one tracheid to another, in its journey from the roots to the leaves.

13. Cells of Coniferous Woods.—All the other coniferous woods are made up in a manner very similar to spruce. They, all, are composed mainly of long tracheids extending vertically, which make up the greater part of the wood, and rays that extend horizontally, which make up most of the remainder of the wood. The pines differ from the spruces in having much larger resin ducts and in the size of the openings in the central ray cells, or the presence, in the hard pines, of toothed walls in the

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TABLE II

FOR THE IDENTIFICATION OF CONIFEROUS (RESINOUS) WOODS

(As seen with the naked eye)

Kind or species of wood	Characteristics								
	Weight per cu. ft., Air dry	Color Heartwood	Color Sapwood	Width Sapwood	Summerwood	Odor	Hard or Soft	Resin ducts	Other Characteristics
Soft or White Pines									
Sugar Pine	27	Creamy to orange brown	Pale straw	1″ to 2″	Not marked	Piney	Soft	Large	
Jack Pine	28 to 34	Reddish to orange brown	Pale straw	2″ to 4″ 1″ to 2″ 2½″ or more	Moderately marked	Piney	Soft to hard	Large	
Norway (Red) Pine									
Lodgepole Pine									
Western Yellow Pine									
Southern Yellow (Long-leaf) Pine	42	Reddish to orange brown	Pale straw	1″ to 2″	Very marked	Piney	Very hard	Large	Usually very resinous
Douglas Fir	34	Red to yellow	Pale straw	1″ or more	Very marked	Resinous	Very hard	Small	
Tamarack (Larch)	36	Dull russett	Pale straw	1″ or less	Very marked	Resinous	Very hard	Small	
Larch, Western	35	Dull russett	Pale straw	1″ or less	Very marked	Resinous	Very hard	Small	
Sitka Spruce	26	Pale red	Pale straw	.....	Mod. marked	Resinous	Soft	Small	
White Spruce	23 to 29	Pale straw	Pale straw	.....	Mod. marked	Resinous	Soft to mod. hard	Small	White Spruce usually has wider annual rings than the other spruces
Red Spruce									
Black Spruce									
Balsam and other true Firs	22 to 28	White	White		Mod. marked	Little	Soft	None	
Hemlock, Eastern	28	Reddish	Reddish		Very marked	Sour	Mod. hard	None	Wood coarse and splintery
Hemlock, Western	28	Reddish	Reddish		Very marked	Sour	Mod. hard	None	Wood not coarse or splintery
Cedar	21	Brown to reddish	Straw to brown	1″ or less	Not marked	Aromatic	Very soft	None	Has characteristic cedar odor
Bald Cypress	34	Brown	Light brown	1″ or more	Mod. marked	None	Mod. hard	None	Smooth surface looks and feels greasy
Yew	45	Orange red	Pale straw		Marked	None	Very hard	None	Very even and fine grained.

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marginal ray cells. Fig. 10 is a diagram of cells of coniferous woods, in which (1) is a tracheid of springwood, (2) is a tracheid of summerwood, and the others are as follows: (3) cell from lining of resin duct; (4) wood parenchyma cell; (*a*) toothed marginal ray cell of hard pine; (*b*) smooth marginal ray cell of soft pine; (*c*) central ray cell, showing piciform pitting; (*d*) central

TABLE III

FOR IDENTIFICATION OF CONIFEROUS WOODS

(With use of the microscope)

Kind of wood	Characteristics				
	Resin canals	Ray tracheids	Wood parenchyma	Spirals	Ray cell pitting
Pines (*Pinus*)	Large, present	Present	Absent	Absent	Very large or large
Spruces (*Picea*)	Small present	Present	(Absent)	Absent	Piciform[4] (=small)
Larches (*Larix*)	Small	Present	(Terminal)[2]	Absent	Piciform[4]
Douglas fir (*Pseudotsuga*)	Present	Present	(Terminal)[2]	Present	Piciform[4]
Fir (*Abies*)	Traumatic[1] only	Present	(Terminal)[2]	Absent	Piciform
Hemlocks (*Tsuga*)	Traumatic[1] only	Present	(Terminal)[2]	Absent	Piciform[4]
Cedars (*Thuya Chamæcyparis*)	Absent	(Absent)	Diffuse[3]	Absent	Cedar-form[5]
Junipers (*Juniperus*)	Absent	Absent	Diffuse[3]	Absent	Cedar-form[5]
Yews (*Taxus*)	Absent	Absent	Absent	Present	Medium

NOTE: A characteristic enclosed in parentheses indicates that one may expect to find it but that it is not invariably present.

[1] Traumatic means due to wounding.

[2] Terminal parenchyma, only at end of annual ring.

[3] Diffuse parenchyma, scattered throughout the annual ring.

[4] Piciform pitting, very small pits as shown in Figs. 9 and 10.

[5] Cedar-form pitting, small round pits as occur in cedar wood.

ray cell, showing pitting as in jack pine; (*e*) central ray cell, showing pitting as in soft pine; the double circles *BP* are the bordered pits, and the small circles *M* are the pits in the fiber connecting with the medullary ray cells.

14. Characteristics of Various Kinds of Coniferous Woods.—Larch is very much like spruce in structure; but it can usually be distinguished from spruce by its greater weight (density), and by the fact that it has a dark-colored heartwood. The true firs, like balsam fir, do not contain resin ducts or marginal ray cells (see Fig. 6). Douglas fir has peculiar spiral (helical) thickenings

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lining the walls of the tracheids; otherwise, it is very similar in structure to spruce; but it has a reddish heartwood and is heavier. Cedar can be easily distinguished from all other woods by its odor.

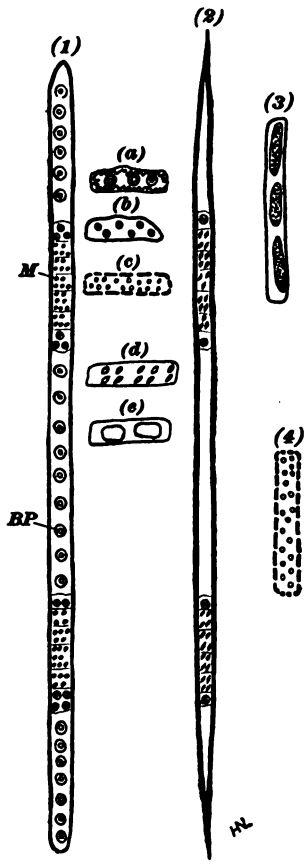

FIG. 10.—Cells of Coniferous Woods, Greatly Enlarged.

(1), tracheid (fiber) of springwood; (2), tracheid (fiber) of summerwood; (3), cell from lining of resin canal: (4), wood parenchyma cell; (*a*), toothed marginal ray cell, as in hard pines; (*b*), smooth-walled marginal ray cell, as in spruce, larch, hemlock, Douglas fir, and soft pines; (*c*), central ray cell showing piciform pitting, as in spruce, balsam fir, larch, hemlock, and Douglas fir; s(*d*), central ray cell showing pitting, as in jack pine; (*e*), central ray cell showing pitting, as in soft pines; *BP*, bordered pit in wall of tracheid; *M*, pits in tracheid wall connecting with ray cells.

For the purpose of identifying the various coniferous woods, consult Tables II and III. The characteristics given in Table II may be distinguished with the naked eye; but a microscope must be used to distinguish those given in Table III.

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THE MINUTE STRUCTURE OF POPLAR WOOD

15. Broad-Leaved, or Non-Resinous Woods.—The woods of the broad-leaved, or non-resinous, trees vary in structure much more than those of the coniferous, or resinous, trees. Since, however, but few of the non-resinous woods are used for making pulp, only poplar, which shows the structure of the woods of this type that are most commonly used, will be described in detail. Figs. 11, 12, and 13 are photomicrographs of small blocks of poplar, birch, and red oak woods, enlarged 20 diameters.

Fig. 14 is a diagram of a small block of poplar wood, greatly enlarged. As will be seen, this wood is made up mostly of wood fibers *WF* that are similar to one another in size and in thickness of the cell walls. These fibers are attached firmly to one another by a layer called the middle lamella *L*; this layer dissolves in the cooking process, and allows the fibers to separate. In addition to these fibers, there are cells with very much larger openings, the **vessels** or **pores** *V*, which are scattered more or less evenly throughout the wood. There are also the medullary rays *M*, which are similar in size to those of spruce wood; but they differ from those of spruce in that the cells have very much larger pits, and the marginal cells are like the central cells. Distinct marginal ray cells with bordered pits are not found in any of the woods of the broad-leaved trees.

16. Identifying Woods of the Broad-Leaved Trees.—The woods of the broad-leaved, or non-resinous, trees may be distinguished from one another with the naked eye, by their weight (density), color, width of sapwood, hardness, size and distribution of pores, size of rays, and, in certain cases, by other special characteristics; for this purpose, Table IV will be found useful.

With the aid of the microscope, the width of the rays, the shape and distribution of the pits, or openings, on the side walls of the pores, the shape of the openings at the end of the pore segments, the position of the cells forming the rays, and, in certain cases, other special characteristics, may be noted in distinguishing one kind of wood from another. The variations shown by the different kinds of wood (visible under the microscope) are given in Table V, but it will be well to describe in detail just what is meant by these characteristics.

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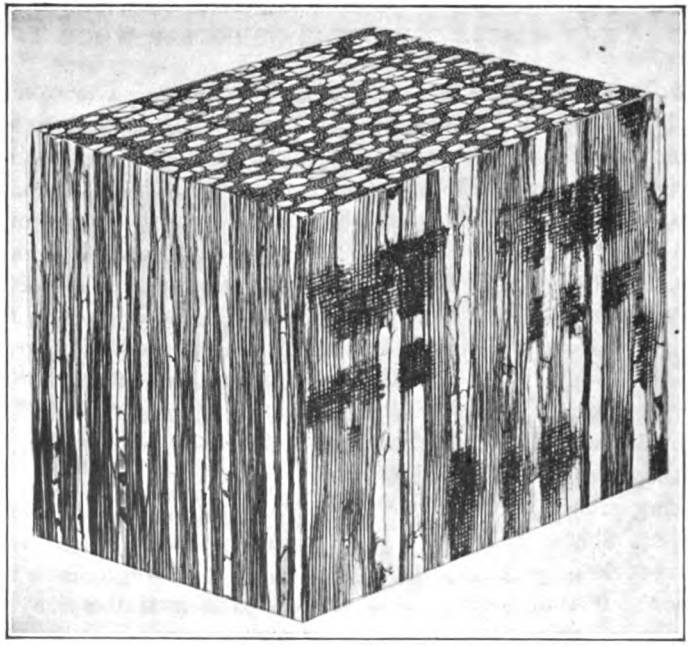

FIG. 11.—Photomicrograph of Block of Poplar Wood. × 20.
(Prepared by the Forest Products Laboratories of Canada.)

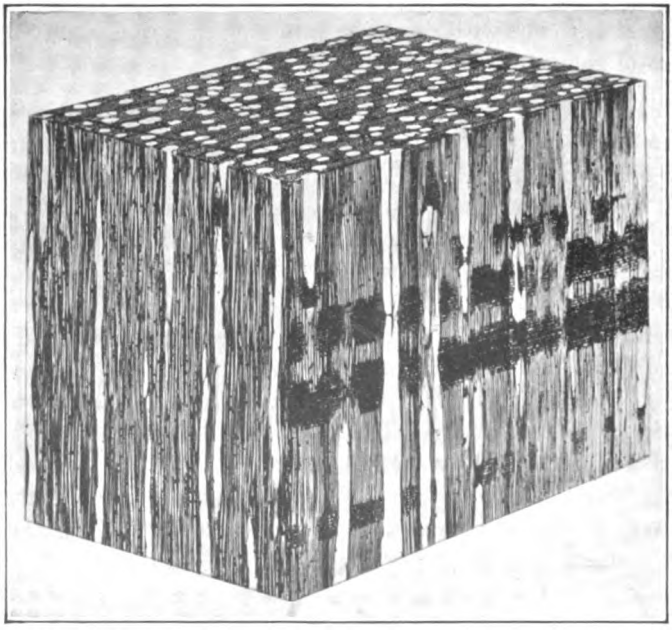

FIG. 12.—Photomicrograph of Block of Birch Wood. × 20.
(Prepared by the Forest Products Laboratories of Canada.)

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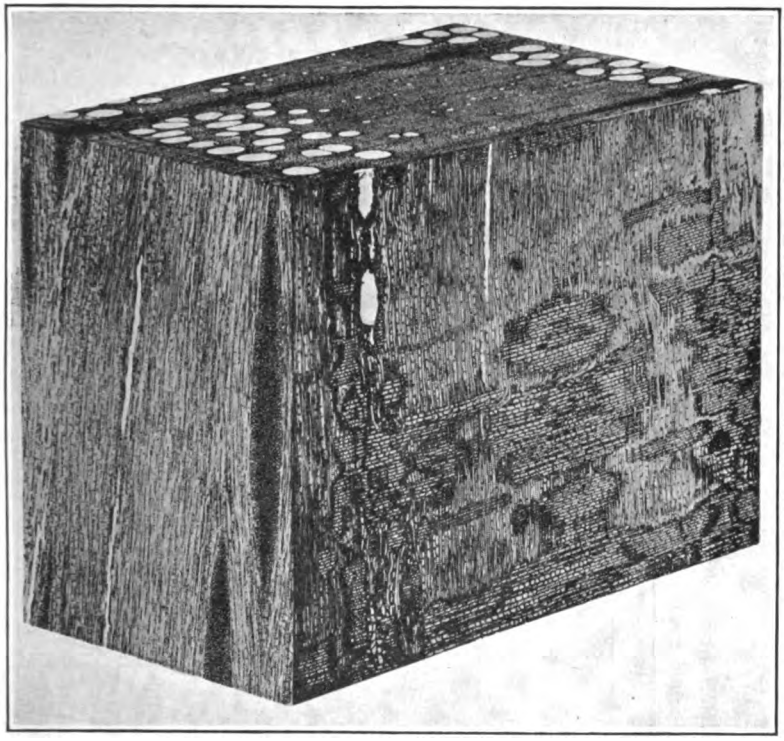

FIG. 13.—Photomicrograph of Block of Red Oak Wood. × 20.
(Prepared by the Forest Products Laboratories of Canada.)

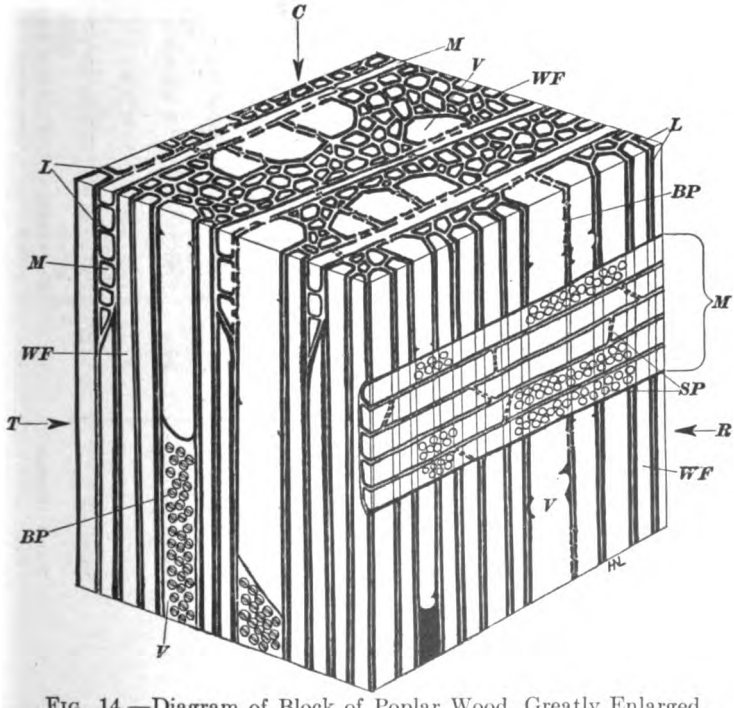

FIG. 14.—Diagram of Block of Poplar Wood, Greatly Enlarged.
C, cross section; *R*, radial section; *T*, tangential section; *M*, medullary ray; *WF*, wood fiber; *V*, vessel or pore; *L*, middle lamella; *BP*, bordered pit; *SP*, simple pit.

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TABLE IV

FOR IDENTIFICATION OF NON-RESINOUS WOODS

(As seen with naked eye)

Kind of Wood	Characteristics							Other Characteristics
	Wt. of oven dry wood per cu. ft. of green volume	Color Heartwood	Color Sapwood	Width Sapwood	Hardness	Pores	Rays	
Poplar, Aspen....	28	Grey white	Not different from heart		Soft	Not visible	Not visible	(All these woods, except Chestnut, are diffuse porous)
Birch.....	38 to 44	Reddish brown or absent	Light yellow	Several inches	Hard	Barely visible	Not visible	
Beech.....	44	Reddish brown or absent	Reddish white	2 to" 5"	Hard	Not visible	Large conspicuous	Pores fewer and smaller in summerwood than in springwood
Maple, hard.....	43	Light reddish brown	Pinkish white	Several inches	Hard	Not visible	Narrow but visible	Widest rays about same width as largest pores
Maple, soft.....	34	Light reddish brown	Pinkish white	Several inches	Hard	Not visible	Narrow but visible	Pith flecks often abundant
Chestnut.....	30	Gray brown	Gray white	½"	Soft	Very large	Not visible	Pores very large in springwood. Ring porous
Gum.....	35	Pale gray brown	Gray white	1" to several ins.	Hard		Not visible	
Basswood.....	25 to 27	Pale creamy brown	Creamy white	1" to several ins.	Soft	Not visible	Visible	
Yellow Poplar Tulip.....	28	Greenish yellow	Gray white	1" to several ins.	Soft	Not visible	Visible	

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TABLE V

FOR IDENTIFICATION OF NON-RESINOUS WOODS

(With use of microscope)

Kind of wood	Characteristics					Other characteristics
	Width of rays	Distribution of pores in summer-wood	Openings on side walls of pores	Openings at end of pore segments	Position of cells forming rays	
Poplar Aspen	1 cell	Evenly scattered	Round, short, slit-like	Simple	Longest axis radial	
Birch	3 cell	Evenly scattered	Round, short, slit-like	Scalariform	Longest axis radial	Pith flecks common
Beech	1 or more	Evenly scattered	Round, short, slit-like	Simple and scalariform	Longest axis radial	Some of rays very broad
Maple, hard	3 or 4	Evenly scattered	Round, short, slit-like	Simple	Longest axis radial	Spirals in pores. Rays on radial surface darker than back ground
Maple, soft	3	Evenly scattered	Round, short, slit-like	Simple	Longest axis radial	Spirals in pores. Rays on radial surface darker than background. Pith flecks common
Chestnut	1	Long, radial rows	Round, short, slit-like	Simple	Longest axis radial	Ring porous. Astringent. taste
Gum	1 to 3	Short, radial rows	Opposite, round or elongated horizontally	Scalariform	Marginal cells with longest axis vertical	
Basswood	4	Scattered evenly or in short radial rows	Round	Simple	Longest axis radial	Elements except rays storied. Spirals in pores
Tulip	3 or 4	Scattered evenly	Elongated horizontally	Scalariform	1 row marginal cells with longest axis vertical	

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17. Cells of Non-Resinuous Woods.—In the block of poplar wood shown in Fig. 14, the rays are only one cell wide; but in most of the non-resinous woods used in the manufacture of pulp, the rays are made up of three or more rows of cells, placed

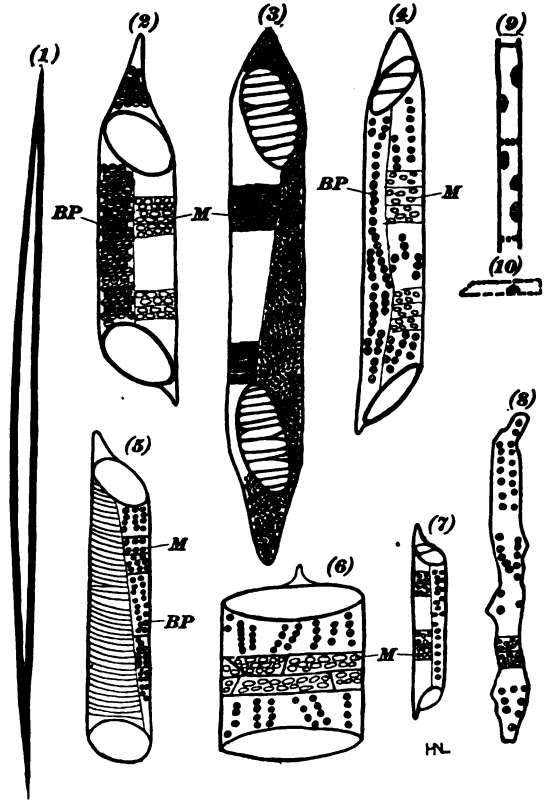

FIG. 15.—Cells of Wood of Broad-Leaved Trees, Greatly Enlarged.

(1), wood fiber from broad-leaved tree; (2), vessel, poplar, with large, clear openings at ends of segment; (3) vessel, birch, with scalariform openings at ends of segment; (4), vessel, beech, with clear or sclariform openings at ends of segments; (5) vessel, maple, with spiral thickenings; (6) vessel, chestnut, springwood; (7), vessel, chestnut, summerwood; (8), tracheid, chestnut, springwood; (9), wood parenchyma cells, which occur to a slight extent in most woods; (10) one medullary cell; *M*, openings in walls of vessels connecting with ray cells; *BP*, bordered pits in walls of vessels.

side by side, which makes the medullary ray as a whole very much larger than it is in poplar. The shape and the distribution of the pits may be seen in Fig. 15. Here (1) is a fiber from a broad-leaved tree; the other numbers are as follows: (2) vessel, poplar, with large clear openings at ends of a segment; (3) vessel, birch, with scalariform openings at ends of segment;

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(4) vessel, beech, with clear or scalariform openings at ends of segment; (5) vessel, maple, with spiral (helical) thickenings; (6) vessel, chestnut, springwood; (7) vessel, chestnut, summerwood; (8) tracheid, chestnut, springwood, (9) wood parenchyma cells, which occur to a slight extent in most non-resinous woods; (10) one medullary ray cell; *M*, openings in walls of pores where they adjoin ray cells; *BP*, bordered pits.

In birch, Fig. 15 (3), the pits are extremely small and very crowded, while in chestnut, they are much larger and more scattered. The special groups of pits that appear as bands on the side walls of the vessels in Fig. 15, show the shape and arrangement of the pits leading from the pores into the ray cells, where the two come in contact in the wood. Comparing the pores of poplar with those of birch, for example, it will be found that where the ends of the segments join in poplar, Fig. 15 (2), there is a large, clear opening, while in birch, Fig. 15 (3), the opening is crossed by bars. Since these bars are similar in appearance to a ladder, they are called **scalariform,** which means *ladder-like.* The presence or absence of these bars is a leading characteristic of the various woods, and from this feature alone, the kind of wood from which the pulp has been made can often be accurately determined. In most woods, the longest axis of the individual medullary rays is radial, as shown in poplar at *M*, Fig. 14. In some woods, however, as stated in Table V, the cells at the margins of the rays have their longest axis extending vertically. In certain woods, for example, maple and basswood, the pores have spiral (helical) thickenings on their inside surfaces, Fig. 15 (5); this latter characteristic is often obscured by the pits, but when seen, it is a sure indication of the kind of wood.

18. The Pores of Non-Resinous Woods.—In most of the non-resinous woods used in the manufacture of pulp, the pores are more or less evenly scattered throughout all the wood, and the wood, in this case, is called **diffuse porous.** Many of the hard woods, however, like chestnut, oak, elm, and hickory, show the pores in the springwood very large and crowded together, while the pores of the summerwood are much smaller and scattered, so that a distinct ring appears, which marks the springwood. These latter woods are called **ring porous,** to distinguish them from the diffuse porous woods. Compare Figs. 12 and 13.

In some of the non-resinous woods, such as chestnut, the cells adjoining the pores, especially those in the springwood, are

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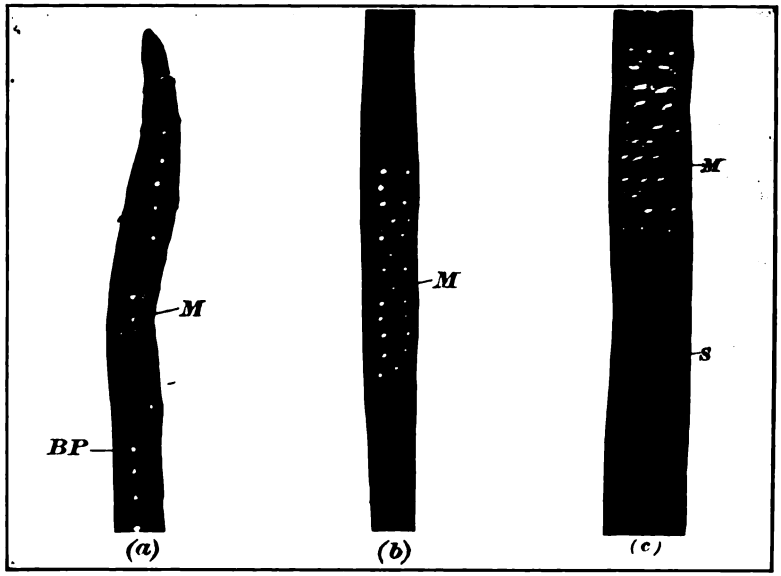

(*a*) Part of a tracheid (fiber) of jack pine showing type of pitting *M* in fiber wall where it adjoins a medullary ray; also bordered pits *BP*, which occur in the fiber wall where it adjoins another fiber. × 150.
(*b*) Part of a tracheid (fiber) of balsam fir showing piciform pitting *M* in fiber wall where it adjoins a medullary ray. × 150.
(*c*) Part of a tracheid (fiber) of Douglas fir showing piciform pitting *M* in fiber wall where it adjoins a medullary ray; also spiral thickenings *S*, which occur in the fiber wall. × 150.

FIG. 19.
(Prepared by the Forest Products Laboratories of Canada.)

FIG. 20.—Poplar Fibers from Mature Wood. × 20.
(Prepared by the Forest Products Laboratories of Canada.)

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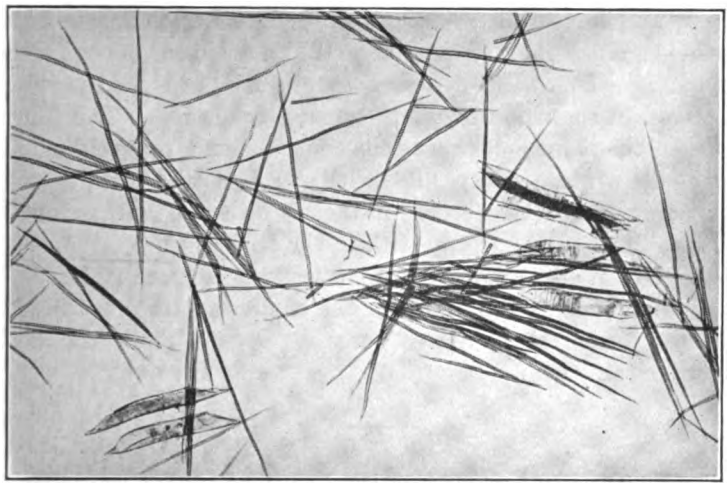

FIG. 21.—Birch Fibers from Mature Wood. × 20.
(Prepared by the Forest Products Laboratories of Canada.)

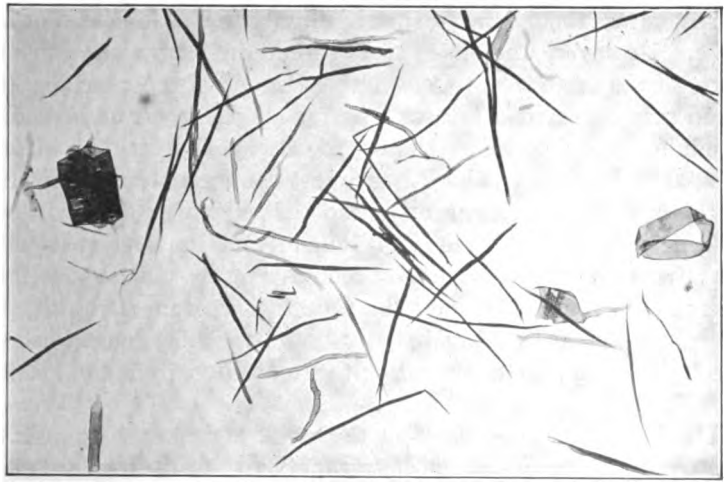

FIG. 22.—Chestnut Fibers from Mature Wood. × 20.
(Prepared by the Forest Products Laboratories of Canada.)

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larger, and have thin walls and bordered pits; these are called tracheids, since they are similar to the tracheids of the coniferous woods. See Fig. 15 (8). Parenchyma (pith) cells are irregularly scattered in the wood of many broad-leaved trees. See Fig. 15 (9). In the sapwood, these cells contain living protoplasm, and during the winter they are filled with starch or oil, which, together with similar substances stored in the ray cells, are used as food by the tree during the early growth in the spring.

Wood of non-resinous, or broad-leaved, trees can always be easily distinguished from that of the coniferous trees by the fact that the former always have pores, or vessels, while the latter never contain them.

LENGTH OF FIBERS

19. Variations in Length of Fibers.—In what follows, the term *fiber* is applied both to the wood fibers of the hardwoods and to the tracheids of the coniferous woods.

As a general statement, it may be said that the average length of the fiber of hardwoods is a little more than one millimeter, or one twenty-fifth of an inch (see Figs. 20, 21, and 22), and the average length for the coniferous woods is three millimeters, or one-eighth of an inch (see Figs. 16, 17, 18, and 19). In both cases, the fibers are, roughly, about one hundred times as long as they are wide. However, the fibers vary much in length in different parts of the same tree. Considering the end of cross-cut log, the wood may be divided into two parts: (1) the wood immediately adjoining the pith, where the fiber is always shorter than in, (2), the part adjoining the bark. In most coniferous trees, the fiber in the first annual ring, around the pith, averages less than one millimeter in length (see Fig. 16*a*, *b*, *c*). In each successive year from the pith, the fiber becomes longer, until about fifty years are covered. Beyond the fiftieth year from the pith, the average fiber changes but little. Again, the fiber length in any one tree varies a little according to its position from the ground (see Fig. 23).

The longest fiber is found in the wood at from ten to twenty feet from the ground, in most trees; above twenty feet or below ten feet, the fiber is found to be progressively shorter. The variation in average fiber length at various heights from the ground

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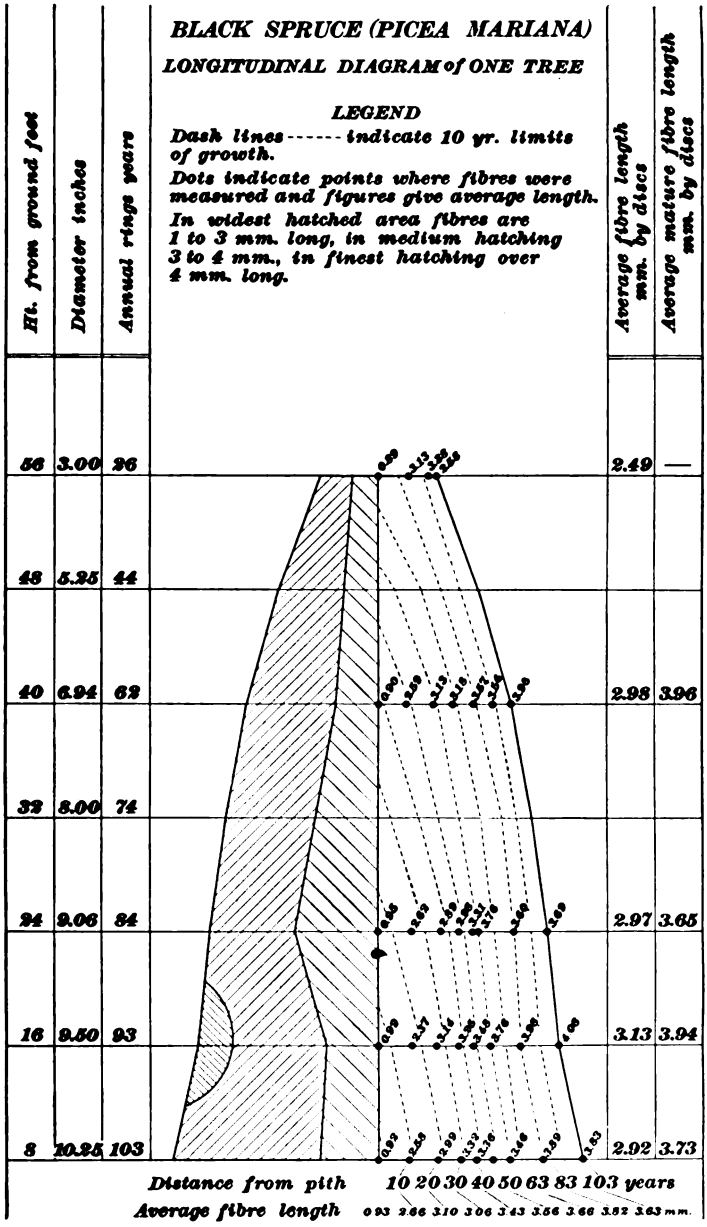
BLACK SPRUCE (PICEA MARIANA)
LONGITUDINAL DIAGRAM of ONE TREE
LEGEND
Dash lines ------ indicate 10 yr. limits of growth.
Dots indicate points where fibres were measured and figures give average length.
In widest hatched area fibres are 1 to 3 mm. long, in medium hatching 3 to 4 mm., in finest hatching over 4 mm. long.
Ht. from ground feet
Diameter inches
Annual rings years
Average fibre length mm. by discs
Average mature fibre length mm. by discs
56 3.00 26 2.49 —
48 5.25 44
40 6.24 62 2.98 3.96
32 8.00 74
24 9.06 84 2.97 3.65
16 9.50 93 3.13 3.94
8 10.25 103 2.92 3.73
Distance from pith 10 20 30 40 50 63 83 103 years
Average fibre length 0.93 2.66 3.10 3.06 3.43 3.56 3.66 3.82 3.63 mm.

FIG. 23.—Longitudinal Diagram of Black Spruce Tree, Showing Average Fiber Length in Various Parts of Tree.

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has been found, in a white spruce tree about 100 years old, to be as follows:

3 feet from the ground	2.50 mm.
8 feet from the ground	3.10 mm.
16 feet from the ground	3.50 mm.
24 feet from the ground	3.25 mm.
40 feet from the ground	3.00 mm.
56 feet from the ground	2.60 mm.
72 feet from the ground	2.40 mm.

A similar variation occurs in trees of all species.

In a horizontal direction, at any height from the ground, the variation in length of fiber in any tree may be illustrated by the following figures from white spruce, 106 years old, at three feet from the ground:

1st annual ring surrounding pith	0.85 mm.
10th annual ring from pith	1.60 mm.
30th annual ring from pith	2.25 mm.
50th annual ring from pith	3.10 mm.
86th annual ring from pith	3.40 mm.
106th annual ring from pith	3.80 mm.

These figures give an idea of the variation in fiber length that may be expected in any tree.

The following figures, taken from various sources, are general averages; they may serve to indicate the variation in average fiber length according to different species.

Coniferous Woods

White spruce (*Picea canadensis*)	3.10
Black spruce (*Picea mariana*)	3.00
Sitka spruce (*Picea sitchensis*)	3.50
Engelmann Spruce (*Picea engelmanni*)	3.00
Balsam fir (*Abies balsamea*)	3.00
Grand fir (*Abies grandis*)	3.20
White fir (*Abies concolor*)	3.50
Douglas fir (*Pseudotsuga taxifolia*)	4.50
Hemlock (*Tsuga canadensis*)	2.90
Western Hemlock (*Tsuga heterophylla*)	2.80
Tamarack (*Larix laricina*)	2.80
Western larch (*Larix occidentalis*)	2.70
Jack pine (*Pinus divaricata*)	3.50
Red pine (*Pinus resinosa*)	3.20
Longleaf pine (*Pinus palustris*)	3.70
Loblolly pine (*Pinus tæda*)	3.00
Shortleaf pine (*Pinus echinata*)	3.70
White pine (*Pinus strobus*)	3.30

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Coniferous Woods

Lodgepole pine (*Pinus murrayana*)	3.20
Western yellow pine (*Pinus ponderosa*)	3.60
Bald cypress (*Taxodium distichum*)	3.30
Redwood (*Sequoia sempervirens*)	5.50

Non-Resinous Woods

White ash (*Fraxinus americana*)	1.20
Aspen (poplar) *Populus tremuloides*)	1.15
Cottonwood (poplar) (*Populus deltoides*)	1.30
Basswood (*Tilia americana*)	1.15
Paper birch (*Betula papyrifera*)	1.20
Yellow birch (*Betula lutea*)	1.50
Beech (*Fagus atropunicea*)	1.20
Chestnut (*Castanea dentata*)	1.00
Tulip tree (*Liriodendron tulipifera*)	1.80
Cucumber tree (*Magnolia acuminata*)	1.30
Black gum (*Nyssa sylvatica*)	1.70
Red gum (*Liquidambar styraciflua*)	1.60
Elm (*Ulmus americana*)	1.50
Maple (*Acer saccharum*)	1.00
Sycamore (*Platanus occidentalis*)	1.70

SOME PHYSICAL PROPERTIES OF WOOD

20. Variation in Specific Gravity.—Table VI gives some physical properties of certain woods when green. It will be noticed that the data for specific gravity and weight per cubic foot are given in a slightly different manner from the usual way of reporting these figures. By multiplying the weight per cubic foot by $1 + x$, wherein x is the amount of moisture in per cent, expressed decimally, (calculated on the oven-dry wood) in the wood at which the weight per cubic foot is desired, the weight per cubic foot at any desired moisture content can be obtained. Thus, to find shipping weight per cord of green wood, say white spruce, it is first necessary to determine or estimate the moisture content. Assuming it is 80% of oven-dry weight $\left(= \frac{.80}{1 + .80} \times 100 = 44.4\%\right.$ of green weight), multiply 21.8 (the weight of a cubic foot from Table VI) by $1 + .80 = 1.80$; the result is $21.8 \times 1.80 = 39.2$ lb. = the weight of one cubic foot of green white spruce. The rough wood will hardly run more than 90 cubic feet of solid wood to the cord; so the weight of a cord of green white spruce is $39.2 \times 90 = 3528$ pounds. Had the moisture

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content been 100% of the oven-dry wood, the cord would have weighed 21.8 × (1 + 1.00) × 90 = 3924 pounds.

The specific gravity varies in a tree, decreasing, in general, from the butt to the top of the tree. The presence of *rotholz* (an abnormal formation of wood in localized sections, due to strain or climate) in coniferous wood increases the specific gravity. It should be remembered that wood is not a solid material, since the cells of which it is composed are hollow; hence, a block of wood is a combination of real substance and of air space. The wood substance itself has a specific gravity of approximately 1.54, but an actual block of wood, as shown in Table VI, has a much lower specific gravity. In fact, the figures show that in ordinary pulp woods, more of their volume is made up of air space than of actual wood substance.

21. Moisture in Wood.—When green wood is allowed to become thoroughly air dry, it still contains a certain amount of

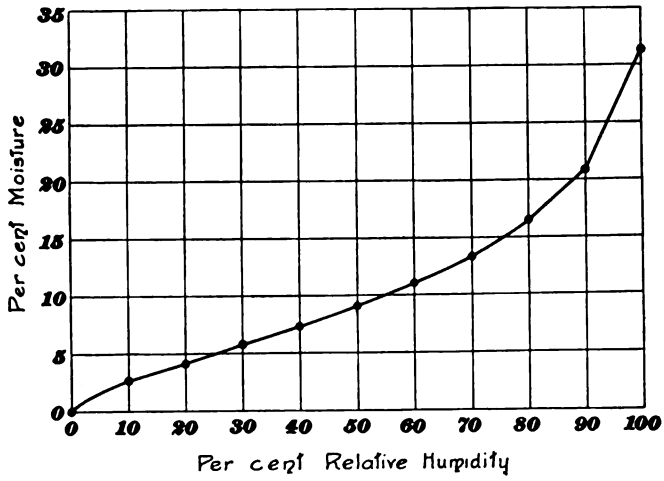

FIG. 24.—Curve Showing the Relation between Moisture in Wood and Moisture in Air Surrounding the Wood.

moisture; but the amount (percentage) of this moisture varies, according to the amount of moisture (relative humidity) of the air surrounding the wood. Fig. 24 is a curve showing the percentage of moisture variation in wood corresponding to different relative humidities of the atmosphere surrounding it; the curve is based on average figures found for several different kinds of wood, at a temperature of about 70°F.

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TABLE VI

SOME PHYSICAL PROPERTIES OF CERTAIN WOODS, WHEN GREEN[1]

Species	Based on green volume and oven-dry weight		Load required to embed 0.444 inch steel sphere to ½ its diameter[3]		Shrinkage in volume from green to oven-dry condition
	Specific Gravity[2]	Wt. per cu. ft. pounds	End	Side	Per cent of Green Volume
White Spruce	0.35	21.8	300	280	13.0
Black Spruce	0.38	23.7	420	360	11.3
Red Spruce	0.38	23.7	420	350	11.8
Sitka Spruce	0.34	21.2	430	370	11.2
Engelmann Spruce	0.31	19.3	250	240	10.4
Balsam Fir	0.34	21.2	290	290	10.8
Grand Fir	0.37	23.1	420	360	10.6
White Fir	0.35	21.8	380	330	10.2
Douglas Fir	0.45	28.0	510	470	12.6
Hemlock	0.38	23.7	510	410	10.4
Western Hemlock	0.38	23.7	540	430	11.6
Tamarack	0.49	30.5	400	380	13.6
Western Larch	0.48	29.9	470	450	13.2
Jack Pine	0.39	24.3	380	370	10.4
Red Pine	0.43	26.8	360	340	11.5
Longleaf Pine	0.55	34.3	550	590	12.3
Loblolly Pine	0.50	31.2	400	450	12.6
Shortleaf Pine	0.50	31.2	490	560	12.6
White Pine	0.36	22.4	300	300	7.8
Lodgepole Pine	0.38	23.7	320	330	11.5
Western Yellow Pine	0.38	23.7	310	320	10.0
Bald Cypress	0.41	25.6	470	380	10.7
White Ash	0.52	32.4	1000	900	12.6
Aspen, Poplar	0.36	22.4	270	320	11.1
Cottonwood	0.37	23.1	380	340	14.1
Basswood	0.33	20.6	280	250	15.8
Paper Birch	0.47	29.3	400	490	16.3
Yellow Birch	0.54	33.6	820	740	16.8
Beech	0.54	33.6	950	820	16.2
Chestnut	0.40	25.0	530	420	11.6
Tulip Tree	0.37	23.1	420	340	11.4
Cucumber Tree	0.44	27.4	600	520	13.6
Black Gum	0.46	28.7	790	640	13.9
Red Gum	0.44	27.4	630	520	15.0
White Elm	0.44	27.4	610	550	14.4
Sugar Maple	0.56	35.0	1000	910	14.5
Sycamore	0.46	28.7	700	610	14.2

[1] Most of the data given in this table were taken from U. S. Department of Agriculture Bulletin 556.

[2] The specific gravity is determined by taking a known volume of green wood and oven-drying it. Then the oven-dry weight of the wood divided by the weight of a volume of water equal to the volume of the original piece of green wood is the specific gravity. The weight per cubic foot is calculated by multiplying the specific gravity by 62.4.

[3] An indication of difficulty in chipping or grinding.

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It will be seen from the curve that when the relative humidity is 70%, say, the moisture in the wood is about 13%, and when the humidity is 100%, the moisture in the wood is about 31.5%.

22. Variation in Strength and other Physical Properties.—The strength and other physical properties of wood vary a great deal, according as the amount of moisture present in the wood is less than 30 per cent. When the amount of moisture is above about 30% (based on oven-dry weight), the strength remains practically the same, no matter how much moisture is present. When the moisture is less than 30%, the strength increases as the moisture decreases. Oven-dry wood may be as much as four times as strong as the same wood containing 30% or more moisture. Other conditions being the same, woods vary in strength according to their specific gravity; that is, the heavier a piece of wood is the stronger it will be.

Wood is a very variable substance, and no two pieces of wood are exactly alike, even if taken from the same log. However, the microscopical structure remains constant, except for the size of the cells, and the physical properties seldom vary over ten per cent in any given species of wood.

23. Bark.—The **bark** of a tree or other plant is the rind or covering of the stem, branches, and roots, as distinguished from the wood. In each year's growth of a tree, there is added one annual ring of bark, which corresponds to the ring of wood. However, since the bark is much softer than the wood, the individual years of growth cannot, in most cases, be distinguished from one another in the bark.

During the first years of the life of a tree, all the bark is composed of living cells; but, as the growth proceeds, the outer part of the bark dies, and with the increase in the diameter of the wood, the bark is stretched and cracked. As a result, the outer surface of the bark of most trees is irregular, furrowed, scaly, or broken into plates. The inner bark, however, always remains living, as long as the tree grows; and it is through the cells of this inner bark that the sugar manufactured in the leaves is transported to the cambium, to make it grow, so it may develop more new wood and new bark. If the inner bark be cut completely around the tree, the flow of sugar food is prevented; the tree then ceases to grow, and it soon dies. The outer bark serves as a protective covering to the delicate inner bark, the

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cambium, and the wood, and it keeps those parts from drying out, and it also keeps fungi and insects from attacking them.

In most trees, a considerable amount of *cork* develops each year in the region of the bark that bounds the living cells; it is from such growth in the cork oak of Spain that the cork of commerce is obtained. In most trees, there is a considerable amount of *tannin* present in the bark, and substances of value as drugs or dye-stuffs are frequently to be found also. But the only pulpwood now commonly used whose bark furnishes any of these materials is hemlock, from which tannin is secured.

In general, the bark of trees is of importance in pulpwood only as it constitutes waste material that must be removed. Although there is some good fiber in it, the proportion is so small, and the difficulty of removing it is so great, that it is uneconomical to attempt to secure it, except for a low grade of fiber used in roofing or similar papers.

24. Glossary and Bibliography.—The glossary at the end of this Section gives the meaning of certain terms used in the preceding and following pages. The bibliogaphy will be useful to those who desire further information in regard to wood and its properties.

QUESTIONS

(1) Name three plants, four resinous trees, and three non-resinous trees used for making pulp and paper.

(2) How can the age of a tree be determined and why?

(3) How does a tree grow?

(4) What are the two main classes of trees?

(5) Is wood an absolutely solid substance like steel or glass? If not, how does it differ from these?

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PROPERTIES OF PULP WOOD

(PART 2)

By J. NEWELL STEPHENSON, M.S. and R. W. HOVEY, B.Sc.

CHEMICAL PROPERTIES OF PULP WOOD

COMPOSITION OF WOOD

25. Principal Source of Cellulose.—Wood is composed principally of **cellulose**; and it is the large proportion of this substance, its fibrous character, and the ease with which it can be obtained in almost any degree of purity, which makes wood the most important source of paper-making material. Only by gross neglect of our forests is there any likelihood that some other material will ever prove more convenient and economical. It is important that the student of pulp and paper making get a clear understanding, as far as our present knowledge permits, of at least the most important of the constituents of wood. Complete discussion of this subject would fill this volume; but a brief presentation of the basic facts regarding the chemical properties of pulpwood is necessary for a proper understanding of the descriptions and explanations in the later Sections, which cover the manufacturing processes. The student is urged to read as many as possible of the references given in the Bibliography, and to study current literature.

26. Chief Constituents of Wood.—The principal physical properties of the commonly used woods, as far as they affect the manufacture of pulp, have been given in Part 1. Attention will now be directed to the more important of the chemical constituents, and of their relation to pulp and paper making. These constituents vary in kind and in quantity with different woods, so that only typical examples will here be considered.

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The more important substances in dry wood are: cellulose, lignin, sugars and other carbohydrates, proteins, fats and resins, tannin, and mineral matter. The amounts of these substances present in wood, and the manner in which they act under the various treatments in the pulp mill, affect the quantity and quality of the pulp obtained.

A knowledge of the chemical properties of wood is important, not only in the manufacture of pulp but also as a guide to the economic utilization of waste liquors from the chemical treatment of the wood; these liquors contain 50 per cent or more of the original wood substance.

Klason gives the following figures for the chief constituents of European spruce wood:

Cellulose	50%
Lignin	30%
Carbohydrates	16%
Protein	0.7%
Resins and fats	3.3%

27. North American woods differ somewhat from European woods, one species differs from another, even two parts of the same tree differ; also, different results are obtained by different analysts and by different methods of analysis. The analysis of wood is one of the most difficult problems in organic chemistry, so it is not surprising that there is considerable lack of agreement among investigators. Some recent results are given below. Johnsen and Hovey analyzed Canadian woods by a method that gave a cellulose product identical with commercial pulp; they obtained the following results, calculated on oven-dry weight of wood:

	Ash, %	Gums etc., %	Cellulose, %	Lignin, %	Fats and resins,[1] %
White spruce	0.25	16.0	56.48	27.60	0.99
Black spruce	0.26	....	50.64	27.55	0.69
Red spruce	0.24	....	52.95	28.45	1.39
Balsam fir	0.28	....	51.60	31.10	1.42
Jack pine	0.18	....	49.24	30.45	1.61
Hemlock	....	....	48.70	26.34	1.72
Aspen (poplar)	0.34	....	57.25	26.33	1.87

[1] Not all from the same sample analyzed for cellulose and lignin.

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Schwalbe and Becker give the following table of the principal constituents of wood and some products of chemical treatment:

	Calculated on dry substance				
	Spruce, Picea excelsa, %	Pine, Pinus silvestris, %	Beech, Fagus silvatica %	Birch, Betula vecrucosa, %	Poplar, Populus tremula, %
Ash	0.77	0.39	1.17	0.39	0.32
Fat, wax, and resin (*a*) Ether extract	0.78	1.92	0.31	0.71	1.08
Fat, wax, and resin (*b*) Alcohol extract	1.52	1.53	1.47	1.09	2.08
Fat, wax, and resin (*c*) Sum of (*a*) and (*b*)	2.30	3.45	1.78	1.80	3.16
Fat, wax, and resin (*d*) Alcohol-bensene extract	2.34	3.32	1.20	1.68	2.87
Methyl value	2.36	2.20	2.96	2.77	2.57
Pectin (according to Von Follenberg)	1.22	1.11	1.75	1.61	1.82
Acetic acid (Schorger's method)	1.44	1.40	2.34	4.65	4.17
Protein, N × 6.25	0.69	0.80	1.05	0.74	0.63
Furfurol	7.49	7.49	14.90	16.08	12.64
Pentosan	11.30	11.02	24.86	27.07	23.75
Methylpentosan	3.00	2.23	1.02	0.84	0.72
Cellulose containing pentosan	63.95	60.54	67.09	64.16	62.89
Pentosan in cellulose	9.55	11.27	20.35	29.40	24.94
Cellulose corrected for pentosan	57.84	54.25	53.46	45.30	47.11
Lignin (HCl method)	28.29	26.35	22.46	19.56	18.24

The cellulose content may vary by as much as 4 per cent in different parts of the same tree, and the resin content by 8 to 25 per cent of the amount present. Also, there is a greater proportion of cellulose in old trees than in young ones. The percentage of lignin is nearly constant throughout a tree. The variation in cellulose content is important, since, as this quantity decreases, there is a greater amount of impurities to be removed; hence, the yield of pulp must decrease.

28. How the Tree Grows.—It was shown in Art. **9** how trees grow, i.e., form wood substance. The first step is the combination of water and carbon dioxide to form sugars. This sugar factory is principally in the leaves, where the green chlorophyl assists the reaction. It is generally believed that an intermediate product is formaldehyde CH_2O, and that these molecules combine with one another, *polymerize*, as the chemists say, to form sugars, starches, gums, cellulose, lignin, etc., by different arrangements of this versatile substance. The intermediate products are mostly colloidal, and they form wood substance by absorption from the cambial sap (which carries them) by the cellulose already formed; that is, they may be said, for want of

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a better explanation, to stick to the surfaces of the cellulose cells or fibers. According to Abrams, plant growth proceeds by the division of each cell in the cambium, giving two cells. The partition between the new cells is the middle lamella, adjacent to which, other walls are formed. With such a variety of substances present, and in various stages of formation, it will be seen that the chemistry of wood is a very complex subject; in fact, new developments and discoveries make it necessary, quite frequently, completely to alter some of our conceptions.

29. Products of Destructive Distillation.—When wood is subjected to destructive distillation, the principal products are charcoal, water, gases (mostly CO_2, but with some that are combustible), wood tar and tar oils, acetic acid, and methanol (wood or methyl, alcohol). All the methanol and much of the acetic acid, it is stated, comes from the lignin. That acetic and formic acid radicals are both present in wood, so that the acids are formed by mild hydrolysis, is shown as the result of treating wood with boiling water. Based on dry wood, there was found:

Kind of Wood	Acetic Acid	Formic Acid
Spruce	1.17–1.53%	0.22%
Pine	1.24–140	0.205
Birch	3.15	0.175

The action of 10% sulphuric acid, at 110°C., produces acetic and formic acids; distillation with 12% hydrochloric acid produces furfurol;[1] this is believed to originate with the pentosans.

30. Treatment of Wood for Pulp Making.—Stated briefly, the chemical processes of pulp manufacture produce, in solution, the soluble substances formed by the hydrolysis of the carbohydrates and lignin; also, acids and their salts are formed by hydrolysis and oxidation of wood substances, and are in part neutralized by lime and soda. Fats and resins are rendered soluble by alkaline treatment; they are only partially affected by the sulphite process, although residues are partly removed from the pulp by careful washing.

The various constituents of wood will now be considered in the order of the relative amounts present; the action of the cooking treatment will be mentioned in this Section and the manufacturing operations will be discussed in greater detail in other parts of this volume.

[1] See *Glossary* for definitions.

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CONSTITUENTS OF WOOD IN DETAIL

CELLULOSE

31. Kinds of Cellulose.—As previously stated, the most important constituent of wood is cellulose. This substance forms the frame work of the tree; it also forms the interwoven fabric of the sheet of paper, when it has been separated from the other substances and reduced to individual fibers.

The physical appearance of cellulose fibers, and some of the other properties also, varies in different trees; but the chemical characteristics, while approximately the same for cellulose from different sources, are not really constant. The chemical wood pulps obtained in the commercial processes are not absolutely identical with the so-called **normal cellulose,** which is represented by purified cotton, because wood pulps always contain a small percentage of the lower carbohydrates. But, with careful manipulation, it will undoubtedly be possible to isolate from any wood a cellulose that will be absolutely identical with the cotton cellulose. In the present state of the art, all fibers are cellulose to the papermaker. It is important to remember that cellulose pulps, on account of being somewhat affected by chemical treatment, are by no means identical. No doubt the future will see important developments, as a result of much needed chemical study of this important and interesting substance; for the present, the matter can be presented only in the light that has been shed by painstaking investigation, and the mind should be kept alert and open to the further revelations that are sure to come.

32. Because of the association of cellulose with other substances present in plants, as fatty and waxy bodies, colloidal carbohydrates, etc. ("pectic" compounds), and lignin, the fibrous parts of grasses and reeds are known as **adipo-celluloses, cuto-celluloses,** and **pecto-celluloses,** while trees have **ligno-celluloses.** It has not been definitely proved, unfortunately, whether these substances are chemically connected or only physically associated with cellulose; this is an important point, since it is necessary to isolate the cellulose by chemical means in the manufacture of pulp by the sulphite, soda, and sulphate processes.

33. The Cellulose Molecule.—The structure of the cellulose molecule is still a matter of controversy, although from analysis, it can be expressed empirically as $(C_6H_{10}O_5)_n$. In this formula, n is

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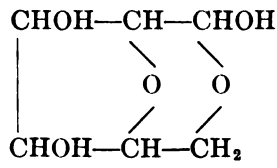
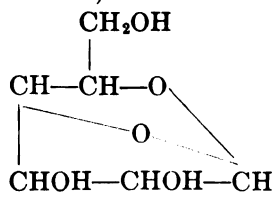
unknown; it is known to be very large, however, and has been given values that make the total molecular weight of the molecule between 5000 and 6000, or perhaps even greater. Note that the unit radical, $C_6H_{10}O_5$, may be written $6CH_2O - H_2O$; that is, it is equivalent to 6 molecules of formaldehyde minus 1 molecule of water. Since the molecule contains twice as many hydrogen as oxygen atoms (the same proportion as in water) and these are associated only with carbon, cellulose is called a **carbohydrate,** i.e., a hydrate of carbon.

Based on its chemical behavior, several structural formulas for cellulose have been proposed, Green's being the best known:



However, Hibbert's formula,



appears to satisfy the requirements of many reactions of cellulose.

34. α- and β-**Cellulose.**—The outstanding characteristic of true cellulose is its resistance to the action of ordinary chemical agents, to atmospheric conditions, and to bacteria and fungi. The inertness of the substance is the basis for its separation from the wood by pulp-making processes; and it is the reason why paper, well made, remains in perfect condition for centuries. There are, however, some enemies strong enough to break up or modify the cellulose molecule.

The highly resistant cellulose of wood, referred to above as very similar to, if not identical with, the cotton cellulose, is known as α-**cellulose.** In addition to this, wood contains less resistant celluloses, which can be dissolved from wood by means of strong alkali. One part of this dissolved cellulose can be precipitated with acid and is called β-**cellulose;** another part remains in solution and is called γ-**cellulose.** Since the commer-

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cial processes for the isolation of cellulose are more severe than the analytical methods of the laboratory, large amounts of the less resistant celluloses are removed in commercial processes. This accounts for the discrepancy between commercial yields and laboratory results of cellulose determinations, which may amount to 10%–20%.

35. Action of Chemicals on Cellulose.—The chemicals used in the pulp mill are in dilute solution; they have but little effect on true cellulose. If, however, cellulose is treated with sodium hydrate, in 17%–18% solution, *mercerization* takes place (see Section 3, Vol. II); and, on washing out the sodium hydrate, the cellulose will be found to be hydrated, differing from the original cellulose in that it takes up more moisture and has also, generally, a higher absorbing power than cellulose. This hydrated cellulose resembles the original cellulose, in that they both have a low reducing power, but the hydrated cellulose is more easily hydrolyzed.

A substance similar to this cellulose hydrate is formed by prolonged maceration in water, when hydrated or *slow* stock is formed in the paper-mill beater. The action of water at high temperatures is somewhat different, in that it tends to hydrolyze cellulose, breaking it down into carbohydrates of less molecular weight, such as gums and sugars.

36. The action of acids depends upon their strength. Strong sulphuric acid, as used in the manufacture of parchment papers, causes a hydration of the cellulose, similar to the reaction with strong alkali; further, the acid has a hydrolyzing effect on the cellulose, transforming it partly into so-called *hydro-cellulose* and, ultimately, into dextrose. Hydro-cellulose is also formed under the influence of weak acids; it does not have the fibrous structure of cellulose, and it has a strong reducing power. Strong nitric and sulphuric acids together form nitrates, ranging from celluloid to powerful explosives. Cellulose acetates are the basis of some photographic films, etc.

37. Strong oxidizing agents, as chlorates, hypochlorites at high temperatures, etc. convert the fibrous cellulose into the structureless *oxycellulose*, which is quite active chemically, but is useless to the papermaker.

Cellulose and hydrated cellulose have little or no reducing power on Fehling's solution (see Section on *Refining and Testing*

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of Pulp). Hydro-cellulose and its hydrates have distinct reducing power. Oxycellulose and its hydrates have strong reducing power.

38. Cellulose is insoluble in ordinary solvents and regents. It is soluble in 72% sulphuric acid, and also in ammoniacal copper compounds (as in the manufacture of Willisden goods), zinc chloride and hydrochloric acid (fiber vulcanizing process), and sodium hydrate and carbon disulphide (viscose process). Nitrocellulose, which is soluble in certain organic solvents, is basis of the Chardonnet silk process, explosives, etc.

The fact that cellulose may be affected by both acids and alkalis is important to both the pulp maker and the paper maker. In the pulp mill, this action makes it necessary to exercise very careful control of the strength of acids and alkaline cooking liquors and of the temperature in the digester, since chemical action is greatly accelerated by heat. In the paper mill, the cooking of rags is an alkaline treatment, and the bleaching of stock is an oxidizing action; either may attack the fiber, if the concentration or temperature of the cooking liquor is too high, or if acid or bleach residues remain in the stock, since at the temperature of drying, these may affect the quality of the paper.

39. Some Properties of Cellulose.—Cellulose is a *colloid;* that is, it gelatinizes by treatment with water and exposes a large surface in proportion to its weight. Thus it *absorbs* substances by what is, in effect, a form of solution, and it also *adsorbs* (holds on its surface) substances, because of its physical nature.

The specific gravity of cellulose may be taken as 1.54; its specific heat is 0.366 (dry); its calorific value is 4223 Cal. (16,758 B. t. u.); its dielectric constant (dry) is 6.7 at 20°C. and 7.5 at 70°C. The dielectric density is about 500,000 volts per centimeter which accounts for the high insulating power of paper. In the presence of water, cellulose acts as an electrolyte.

Certain filamentous fungi (thread-like molds) that are present in soils can dissolve cellulose, thus returning mature plant substance to nature once more in the growth cycle. Some bacteria also dissolve cellulose. The by-products of such action are decomposed into carbon dioxide, methane, and hydrogen.

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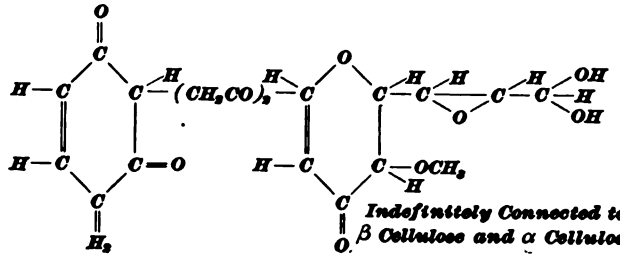
LIGNINS AND LIGNO-CELLULOSE

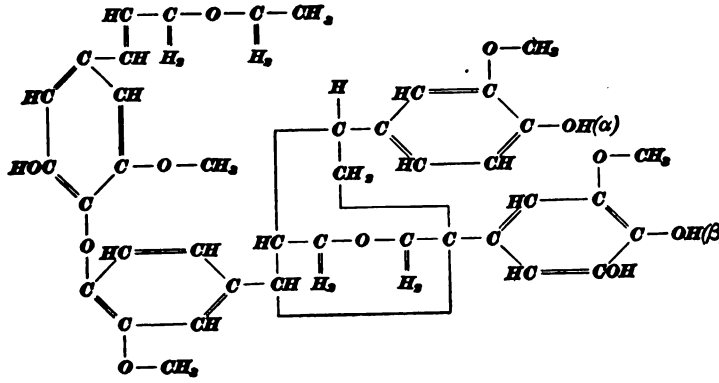
40. Molecular Formulas for Lignin.—Closely associated with cellulose, probably combined with it by a weak chemical connection, is **lignin,** the combination being called **ligno-cellulose.**

Since lignin and coniferyl alcohol have somewhat analogous reactions, Klason has considered lignin to be a condensation product of several molecules of this alcohol, with the formula $C_{40}H_{42}O_{11}$. But lignin is hardly a uniform compound, and recent researches by Klason appear to indicate at least two lignins in spruce wood—**α-lignin** $C_{22}H_{22}O_7$ and **β-lignin** $C_{19}H_{18}O_9$, the former representing about 63% and the latter 37% of the total lignin.

Without prescribing the nature of the bond, Cross and Bevan suggest the following structural formula as satisfying best the reactions that lignin is known to give:



Chambovet has recently proposed (*Paper*, Feb. 9, 1921) the following formula for lignin:



These formulas for lignin are attempts to show graphically the structure of the substance, in so far as this has been revealed by chemical research. When one pauses to consider that the actual

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structural formula for water is even now a matter of controversy among chemists, it is easy to see that the structure of the lignin molecule is a difficult and complex problem of organic chemistry. In fact, the whole subject of the chemistry of wood is a most attractive and fertile field for scientific investigation.

41. Formation of Lignin.—The formation of lignin takes place in young tracheids during growth. There is more lignin in wood of slow growth than in wood of quick growth. Since lignin and coniferyl alcohol have somewhat analogous reactions, some authorities assume that lignin is derived by condensation and oxidation of four molecules of this alcohol.

Lignified cell walls are disintegrated by some bacteria and some fungi, as Penecillium glaucum, Meruleus lacrimans, etc. Animals can digest a part of the lignin in woody plants.

42. Effect on Lignin of Chemicals and Cooking.—In the alkali cooking process, the lignin is oxidized or decomposed, forming alkali salts of lignin acids. These acids may be at least partly precipitated from the alkaline liquors by acids, and they differ from each other in their solubility in alcohol. The sulphite process is explained by the fact that sulphurous acid is added to the unsaturated carbon atoms of lignin, with the formation of ligno-sulphonic acids, which are present in the waste liquor as calcium salts. Two ligno-sulphonic acid compounds have been separated from the waste liquor. The similarity of this reaction to the addition of sulphurous acid to aldehydes and ketones suggests the presence of free carbonyl groups $= C = O$, which can add H_2SO_3 and form $= C\begin{matrix}-OH\\-HSO_3\end{matrix}$

43. Detection of Lignin.—The presence of lignin is shown by several distinct color reactions: aniline salts give a yellow color; ferric chloride gives green; iodine, in potassium iodide, gives dark brown; ferric chloride and potassium ferricyanide (1:1) gives dark blue-black; phoroglucin + HCl gives a red colored compound, which is not decomposed by water. Another characteristic lignin reaction is the yellow color produced by chlorine gas, which changes into a purple on the addition of sodium sulphite. The chlorine forms with lignin a lignin chloride $C_{19}H_{18}Cl_4O_9$, which is soluble in sodium sulphite and in alkali. Simultaneously with this reaction, an oxidation of the lignin occurs.

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The methoxyl content is also characteristic of lignin, and may be determined by distillation with hydriodic acid.

OTHER CARBOHYDRATES

44. Soluble and Insoluble Carbohydrates.—Owing to the manner of formation, it is to be expected that wood will contain a variety of carbohydrates. Besides the highly inert cellulose, there are two general classes: those carbohydrates that are insoluble in water, but are soluble in dilute acids and alkalis; and those that are soluble in water. The first class comprises the **hemi-celluloses.**

The soluble carbohydrates are mostly sugars, such as mannose, arabinose, galactose, xylose, etc. Besides those present in raw wood, the cooking process forms sugars by hydrolysis of certain gums; as hexoses from hexosans $(C_6H_{10}O_5)_n$ and pentoses from pentosans $(C_5H_8O_4)_n$, n being unknown in each case. The hexoses include the fermentable sugars present in sulphite waste liquor; they may amount to 13.3% of the wood, of which 61%–75% is fermentable. These sugars are destroyed by high temperatures at the end of the cooking, and the fermentable sugars go first.

45. The Hemi-Celluloses.—The hemi-celluloses are more easily hydrolyzed by dilute acids then the true celluloses, and are thus converted into the sugars found in the waste cooking liquors. The principal hemi-celluloses in wood are pentosans, frequently accompanied by hexosans, such as mannan and galactan.

The most frequent pentosan is xylan, or wood gum, which gives xylose on hydrolysis, usually with small quantities of arabinose. Distillation with 12% hydrochloric acid gives methyl-furfurol, as well as furfurol, thus indicating that methyl pentosans are also present in wood.

The amount of these substances varies between the hardwoods and the conifers, as a class, but is fairly constant for trees in each class. For example, pentosans in hardwoods are about 22%–26% and in conifers 8%–9% of the dry wood; hexosans are about 3%–6% and 13%, respectively.

According to cooking conditions, these gum-like carbohydrates are charged to sugars or saccharinic acids. In the sulphate

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process, methanol, methyl sulphide, and methyl mercaptan are also obtained. Fir is said to give more mercaptan than spruce.

46. Fats and Resins.—Fats and resins in pulpwoods are important, principally for the trouble they cause. In long leaf pine, there is enough **resin** to make its recovery attractive for commercial use, by treatment of the chips. Mills using this wood and some European mills, recover rosin from spent sulphate liquor. In other conifers, the amount of resin is small, and it varies with the species; there is practically none in hardwoods.

The resins in pulpwoods are of slightly varying composition, but are practically the same as common **rosin** (colophony), the principal constituent of which is the anhydride of abietic acid. **Turpentine** also is frequently associated with rosin, and it can sometimes be recovered from pulpwood. Cymene, or spruce turpentine collects on the surface of the condensate when the relief gases from sulphite digesters are run through a cooling coil. It is an oily liquid, of pungent odor, which is better removed, since it tends to contaminate the pulp, if allowed to go back into the liquor with the recovered sulphur dioxide gas.

47. Much interest has been shown in this subject lately, and investigations have shown that the total extract of wood by organic solvents, instead of being all rosin, is about half **fat.** It has been further shown that the fat, in the presence of resins, is the principal cause of rosin troubles in the paper mill. If freshly cut wood is extracted with ether and then with alcohol, the ether will contain most of the fats, and it will be more fluid and sticky than the darker alcohol extract, which will contain the solid rosin acids. The fats can be removed from both these extracts by treatment with petrolic ether. The fats are largely combinations of glycerine, formed from sugars present in the wood, and oleic and linoleic acids, probably formed from aldehydes in the course of the sugar formation in the trees.

48. When wood is stored, changes take place in it, whereby the amounts of both the ether and alcohol extracts decrease. What is more important, these substances are changed by oxidation to harmless products. This is an argument for well-ventilated storage of wood, and for drying chips by hot air.

There is more fat and resin in pine than in spruce. Sieber gives:

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	Seasoned wood		Fresh wood
	Fat (%)	Resin (%)	Fat and Resin (%)
Spruce	0.50	0.48	2.54
Pine	1.43	1.11	4.90

This investigator also found that only 4.2% of these substances was removed in cooking, while the cooking process removed 51.8% of the wood; and the bleaching process removed 15%; consequently, the percentage of fat and resin in pulp is higher than in wood, and the proportion of fat is also higher in pulp. Caustic soda will remove much of the resin, but it has a tendency to make the fibers yellow. In the paper mill, the resin particles seem to be coagulated by the insoluble fat; and since this is sticky (particularly so in summer), these lumps are caught on the screens or are passed on to the machine. Here they may cause the paper to stick to the press rolls; or they may fill up the holes in the wire, or the pores of the felts.

Mechanical pulp (groundwood) contains all the wood, except possibly a portion of the water-soluble substances, which may have been dissolved during driving or storing of the wood. The resin in paper made therefrom is less troublesome than resin that has been through the sulphite-pulp mill.

Recent investigation on resins of Canadian woods gives results that may be summed up in the following table:

RESINS IN CANADIAN PULPWOODS

	Per cent (based on oven-dry wood)		
	Ether (Soluble)	Alcohol (Soluble)	Total Resin
Black spruce	0.3–0.4	0.3–0.4	0.6–0.8
White spruce	0.3–0.6	0.4–0.5	0.7–1.1
Balsam fir	0.6–0.8	0.8–1.2	1.4–2.0
Jack pine	0.9–1.5	0.5–0.8	1.4–2.3

The per cent of extract soluble in petrolic ether is higher for jack pine and balsam fir than for the spruces; the averages are:

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0.4–0.5 per cent for the spruces, 0.6–0.7 for balsam fir, and 0.8–1.2 for jack pine.

49. Waxes.—A wax-like substance that exists in the walls of wood cells is **cutin.** **Suberin,** a modification of cutin, impregnates the cellulose walls of cork cells (present in the bark of all trees), and it makes them and the bark quite impervious; it is a mixture of fats and glycerides of stearic and phelonic acids, together with cerin, or cork wax. The waxes cannot be oxidized or hydrolyzed.

50. Tannins.—Tannins are present in all woods, the bark containing the greater proportion of them. They also occur as solutions in the wood cells. A hot climate favors tannin formation.

The bark of black spruce contains 7.2% tannins; Engelmann spruce, 12.6%–20.6%; Sitka spruce, up to 17.5%; Douglas fir, 7.2%; Eastern hemlock, 11%–13.1%; Western hemlock, 10%–14.4%; larch, 1.6%. Where wood is driven or stored in water, much of the tannin is extracted. Hardwoods as a rule contain much more tannin than conifers; birch bark has 10%; chestnut, about 15%; oak (smooth bark), 19%; quebracho, 50%. Tannins are also used as mordants in paper and textile mills and for inks.

Among other substances derived from bark, for medicinal or commercial use, are cascara, cinnamon, dyes, quinine, sassafras, etc. These substances are useless to the paper maker, but they are interesting and often valuable as by-products.

The bark of hemlock is the most important source of tannin from woods used in pulp making; oak bark is another important source, but oak is not a pulpwood. The bark is peeled off and sold by the cord; or, it is extracted with water and the extract is sold for its tannin content. The waste liquor from sulphite pulp, especially that derived from hemlock, contains considerable tannin material; this liquor, evaporated to 50% consistency, finds a ready market. Tannin value is dependent not only on the actual tannin present but also, somewhat, on *non-tans*, which impart certain qualities to leather. Chestnut wood is largely used in the Southern States for soda-pulp making, and the tannin is recovered by preliminary extraction of the chips. Chestnut wood is the principal source of tannin in the United States.

51. Miscellaneous Substances.—Among other substances present in pulpwoods are proteins (nitrogenous substances), coloring matters, turpentine, wood oils, and mineral matter. Turpentine can be recovered from the treatment of certain

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pines; the other substances mentioned are too small in amount to require consideration by the pulp maker; they are practically all removed by the cooking process.

EFFECTS OF PULP-MAKING PROCESS

52. All the Wood Not in the Pulp.—A brief statement will now be made regarding the effects of the pulp-making process on the various constituents of the wood, the purpose being merely to guide the student's thought in the study of manufacturing processes. Reactions mentioned can only be stated as characteristic of classes of compounds. The student should be on the look out for new developments, and, where possible, should investigate these subjects on his own account.

None of the substances in the bark need here be considered, since they are all removed with the bark in barking and cleaning the wood. Furthermore, some of the soluble materials in the wood are partly dissolved by water during transportation and storage.

Mechanical pulp (groundwood) contains all the wood except the bark and substances lost by solution. Some of the constituents may change by oxidation during storage, and this change may continue, even after manufacture into paper.

53. Object of Chemical Treatment.—The object of the chemical processes is to remove all constituents of the wood, which would in any way diminish the value of the cellulose for making paper. Recent work has shown that the middle lamella is resolved, thus separating the individual cells. Either acid or alkaline liquor may be used for the cooking, and details of the processes are given in the later Sections. In so far as our present knowledge permits, the action of these liquors may be summarized as follows:

54. Results of the Processes.—Sugars are immediately dissolved and may be destroyed under certain cooking conditions; sugar acids result from oxidation.

Carbohydrates of higher molecular weight, as pentosans and hexosans, are hydrolyzed to aggregates of lower molecular weight, such as dextrins, which, in turn, and in company with other gums, are convertible into sugars, some of which are fermentable and are a source of ethyl alcohol. Acids, also, are formed from carbohydrates, due to the effect of oxidation.

Acids, whether in the wood or produced during manufacture,

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may dissolve as such, or they may form combinations with the bases present in the liquor; the resulting substance is usually soluble.

Fats may be hydrolyzed to form acids, which, especially in the alkaline processes, readily form soaps (saponify). Resins are also saponified by alkalis; but, in the acid process, much of the fats and resins pass into the pulp. Substances of turpentine character distill off with the steam.

Tannins, proteins, etc. either dissolve or are held in suspension after being released by the cooking.

Lignin is changed to acids, which combine with the bases in the liquor. In the sulphite process, there is an addition of sulphurous acid to the lignin, as free carbonyl groups, $=C=O$, apparently without very extensive breaking down of the lignin. There is more drastic action in the alkaline processes, where, as was shown in Art. **42,** the lignin is resolved into at least two acids. The alkaline processes are applicable to more varieties of wood, than the sulphite process; and the drastic effect of the alkali in the soda process is modified by the development of the sulphate process, as will be shown in later Sections, where the action of the sodium hydrate in the former and of the sodium sulphide in the latter are fully explained. Some minor decomposition products are formed in both processes, due to the splitting off and conversion of side groups, as methoxyl—OCH_3, etc. The removal of the lignin and gums leaves the cellulose practically isolated.

The less resistant celluloses (β and γ) are largely removed during cooking, due principally to the hydrolytic action of both types of cooking liquor. The extent to which cellulose itself is attacked depends on how drastic the cooking conditions are and, later on, upon the care exercised in the control of the bleaching operation. Bleached pulp may contain only 80%–90% α cellulose, showing that commercial pulps are uncertain mixtures.

QUESTIONS

(1) In what important chemical characteristics do (*a*) conifers differ from hardwoods? (*b*) spruces from pines?

(2) What is the most important part of wood to the paper maker?

(3) Name a possible use for the sugar in wood.

(4) With what substances is cellulose associated closely in trees and plants? Name the compound celluloses so found.

(5) Name three chemical agents that affect cellulose.

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GLOSSARY

Acetyl. The name of the radical CH_3CO-, considered to exist in combination in wood.

Adipo-cellulose. A compound cellulose containing certain fatty substances.

Alpha (α). Greek letter prefix used to denote the most resistant form of cellulose found in, or produced from, plants.

Ammoniacal. Containing ammonia.

Aniline. A basic substance recovered from coal tar. Its salts, as the sulphate and chloride, form a bright yellow color with lignin.

Annual ring. The ring of wood added each year to the trunks and roots of trees.

Arabinose. A sugar. Has a higher molecular weight than cane sugar.

Bacteria. Minute living organisms that cause chemical action to take place in the tissues of plants and animals. Some are the cause of disease. Most of them are killed by chlorine.

Bark. The rind or covering of the stems, branches, or roots of tree or plant.

Beta (β). Greek letter prefix used to denote a less resistant form of cellulose. β-cellulose is largely removed in making chemical pulp.

Bisulphite. Name of the process, and of the liquor, by which sulphite pulp is produced.

Bordered pit. An opening in the wall of certain fibers called tracheids, that appears to have a border or circle around it.

Cambium. The ring, or zone, of tender growing cells between the bark and the wood.

Cell. One of the minute units, or elements, of various forms, of which plants are formed.

Cerin. A wax-like substance found in the bark of certain trees.

(de) Chardonnet process. Nitro-cellulose is dissolved in an organic solvent, extruded as a fine stream, and precipitated as a thread.

Chlorophyl. The green coloring matter in leaves, which assists in the combination of water and carbon dioxide, to form substances from which wood substance is produced.

Colloid. Resembling jelly or glue; uncrystalline. Starch is a typical colloid.

Colophony. Rosin.

Conifer. A tree of the pine family, so called from its bearing cones.

Coniferous. Cone bearing; of, or pertaining to, the pine family.

Coniferyl. An alcohol of high molecular weight. It is related to lignin and to vanillin, the active principle of the vanilla bean. It occurs in combination with glucose in the cambial sap of some conifers.

Cross section. A section of a body at right angles to its length.

Cutin. A wax-like substance found in plants in combination as cutocellulose.

Deciduous. Not persistent, falling away, as the leaves of trees in the autumn.

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Dextrin (or *dextrine*). A carbohydrate with adhesive properties, formed by hydrolysis of starches, etc. It can be converted into dextrose.

Dextrose. Glucose, or grape sugar $C_6H_{12}O_6$. It is important as a food stuff and as a source of alcohol.

Dielectric. Resistant to passage of electricity.

Diffuse porous. Said of wood whose pores are nearly uniform in size and more or less evenly distributed throughout both spring and summer wood.

Epithelium. The somewhat modified parenchyma cells lining certain inter-cellular cavities, as the resin ducts.

Fats. Compounds of glycerine and organic acids; these are glycerides.

Fehling's solution. A solution of copper sulphate, so prepared that the copper precipitated therefrom by reduction, is a measure of certain substances in terms of dextrose.

Fermentation. The process by which sugars are converted to alcohol.

Fibro-vascular bundles. The strands that make up the framework of common herbaceous plants.

Filamentous. Thread-like (pertaining to fungi).

Formic Acid. HCOOH, the first and strongest acid of the series of which it and acetic acid are most important. Formed by oxidation of methyl alcohol and formaldehyde, and by destructive distillation of wood.

Formyl. The radical group HCO−.

Furfurol (or *furfural*) (furfuraldehyde). A compound $C_4H_3O{\cdot}CHO$ of which 4 carbon atoms and 1 oxygen atom form a ring, to which is attached the aldehyde group—CHO. It is a colorless, oily liquid of agreeable odor.

Fusiform. Thick, but tapering toward each end. Fusiform ray is a medullary ray that is tapered at the ends.

Galactan. A hexosan $(C_6H_{12}O_6)_n$, which on hydrolysis yields the sugar, galactose, which is fermentable.

Gelatinous. Having the nature of jelly.

Glyceride. See fats.

Growth ring. Annual ring of growth; added to the trunk of a tree each year.

Gums. Carbohydrates that are sticky, like dextrin.

Heartwood. The dead central portion of the trunk or of a large branch of a tree; often, but not always, darker colored than the outer sapwood.

Hemi-cellulose. Non-fibrous carbohydrates that are comparatively resistant to hydrolysis.

Hexosans. A sugar containing 6 carbon atoms in its radical, as galactan.

Hydrated. A substance that has had a molecule of water added to its molecule.

Hydrolysis. The splitting apart of a molecule in the presence of water, whereby the hydrogen unites with one part and the hydroxyl with the other.

Lignin. The principal non-cellulose constituent of wood; also called lignone.

Ligno-cellulose. The combination of lignin and cellulose occurring in wood. It is broken down by hydrolysis and oxidation in isolating cellulose by the chemical processes.

Linoleic acid. Occurs in combination with glycerine in linseed oil. It is this acid which enables varnish to absorb oxygen and form a hard film.

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Medullary ray. Plates of cellular tissue radiating from the pith to the bark.

Mannose. A hexose sugar.

Meruleus lacrimans. A fungus that destroys wood.

Mercaptan. A mercaptan has the same formula as an alcohol when SH is substituted for the hydroxyl. Thus, ethyl mercaptan is C_2H_5SH and ethyl alcohol is C_2H_5OH. Mercaptans are ill-smelling substances formed in cooking wood by the sulphate process.

Mercerization. Treatment of cotton thread by sodium hydrate, whereby the thread becomes glossy.

Methanol. Methyl, or wood, alcohol.

Methoxy. The group CH_3O-.

Nitro-cellulose. A combination of cellulose and nitric acid. Mono-, di-, and tri- nitro-celluloses are formed.

Non-porous. Said of wood whose fibers are all similar in size and shape, without pores or vessels. All coniferous woods are non-porous, while all broad-leaved trees have porous wood.

Oleic acid. Occurs as the glyceride in olive oil; it causes rancidity.

Oxycellulose. A structureless substance, formed by drastic action of oxidizing agents on cellulose.

Parenchyma. Soft, more or less thin-walled, cellular tissue of plants, usually containing living protoplasm in growing parts of the plants.

Pectin. In some plants, the principal non-cellulose constituent; present as pecto-cellulose, corresponding to ligno-cellulose of wood.

Penicillium glaucum. A mould that grows on moist wood.

Pentosans. Carbohydrates of the general formula $(C_5H_8O_4)_n$, which yield pentoses (sugars of the formula $C_5H_{10}O_5$) on hydrolysis.

Phloroglucin. An organic compound that gives a reddish coloration with lignin.

Piciform pits. Small pits in ray cells, as in spruce.

Pit. An opening or depression in a cell wall or fiber.

Pith. The softer, central part of a twig or stem.

Pith flecks. Dark marks in wood due to cavities made by the larvæ of certain insects working in the cambium.

Polymerize. To form a substance of higher molecular weight by the union of two or more molecules of the same substance.

Pores. The large openings, or vessels, which occur in the wood of broad-leaved trees.

Proteins. The constituents of plants and animals which contribute nitrogen to the food stuffs.

Protoplasm. The living matter of plant cells, similar to flesh in animals.

Ray. Short for medullary ray.

Ray cell. A cell of a medullary ray.

Ray tracheid. A tracheid, i.e., a cell of bordered pits, found in the medullary rays of some coniferous woods.

Resin. A substance found in trees, or prepared synthetically, which has the properties of rosin.

Resin cell. A cell that secretes resin.

Ring. The annual growth, or increment, of a tree.

Ring-porous. Said of wood whose large pores, or vessels, are collected

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into a row or band in the spring growth of each annual ring; this is one of the distinguishing features of certain broad-leaved trees.

Rosin (colophony). The hard substance left after the distillation of turpentine from the oily sap exuded by certain pines. Principally abietic acid. Used in sizing paper, making soap, etc.

Rotholz. A darker colored, denser, and harder part of one or more annual rings which sometimes occurs in coniferous woods.

Saccharine. Relating to sugar. Saccharinic acids are formed by oxidation of sugar.

Sapwood. The living outer portion of the trunk or of a large branch of a tree, lying between the heartwood and the bark; or, if no heartwood is present, all the wood of the trunk or branch of a tree.

Scalariform. Having markings or structure suggestive of a ladder.

Soda process. The process of making soda pulp; the principal chemical used in the cooking liquor is sodium hydrate, derived from sodium carbonate, or soda ash.

Spirals. A term applied to the helical thickenings of the tracheids or vessels of certain woods.

Springwood. The wood produced early in the growing season of each year, characterized by larger openings and with thinner walls in the tracheids, fibers, and vessels than the later growth (summerwood) of each annual ring.

Starch. The name of a series of carbohydrates of the same general formula as cellulose $(C_6H_{10}O_5)_n$. Starches are non-fibrous and differ considerably, according to their source. Grains are principally starch.

Stearic acid. The acid whose glyceride makes up many hard fats.

Sugars. Carbohydrates of comparatively low molecular weights; they have a characteristic sweet taste.

Suberin. A modification of cellulose, allied to cutin, contained in cork.

Sulphate process. The process of making sulphate pulp; the principal chemical used is sodium sulphate.

Sulphite process. The process of making sulphite pulp; the principal chemical used in the cooking liquor is calcium bisulphite.

Tangential section. A longitudinal section of a body at right angles to one of its radii, as made by slicing off the outer part of the trunk of a tree.

Tannins. Substances that have the property of hardening hides in the production of leather.

Toothed. With teeth or short projections.

Trachea. The pores or vessels as in the wood of broad-leaved trees.

Tracheids. The long, narrow cells of which coniferous woods are largely composed, characterized by the presence of bordered pits. These cells, which are commonly called fibers, are the important part of wood used in papermaking.

Transition. Change, as from springwood to summerwood.

Transverse. Said of a wood section made at right angles to the axis of the trunk or stem; across the grain, or cross cut.

Traumatic. Caused by wounding or bruising.

Trunk. The main stem of a tree.

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Tylosis. A growth, frequently exhibiting repeated cell division, intruding within the cavity of a duct or vessel from a contiguous growing cell.

Uniseriate. In one row or series.

Veins. Threads of fibro-vascular tissue in a leaf or other part of a plant.

Vessel. One of the segments of the tubes that extend vertically throughout the wood of the broad-leaved trees.

Wood. The hard part of the stem of a plant lying between the pith and the bark.

Wood elements. The cells, or units, making up the wood.

Wood fibers. Long, slender cells, with thick walls and narrow cavities, which make up the body of the wood of broad-leaved trees; these are the important part of the wood used in papermaking.

Wood parenchyma. Cells, or elements, of wood, containing living substance (in the sapwood), and extending end to end. They frequently contain starch or oil.

Xylan. The pentosan from which the sugar xylose is derived by hydrolysis.

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PROPERTIES OF PULP WOOD

EXAMINATION QUESTIONS

(1) What determines the value of a plant as raw material for pulp making?

(2) (*a*) How does the structure of other fiber-producing plants differ from that of wood? (*b*) Which give the highest yield of fiber?

(3) Name some of the characteristics by which a specimen of wood may be identified (*a*) with the naked eye; (*b*) using a microscope.

(4) (*a*) Of what elements or parts are coniferous woods composed? (*b*) How are the different elements arranged in the wood? (*c*) When wood is cooked, why do the fibers separate from one another?

(5) How could you distinguish (*a*) a resinous from a non-resinous wood? (*b*) poplar from birch? (*c*) spruce from fir?

(6) What is the approximate average length (*a*) of coniferous fibers? (*b*) of fibers of broad-leaved trees? (*c*) Do fibers differ in length in the same log? (*d*) if so, how?

(7) (*a*) Which is the stronger, wet wood or dry wood? (*b*) In general, which is the harder, a light wood or a heavy wood?

(8) What are the meanings of the following terms: (*a*) annual ring? (*b*) cambium? (*c*) heartwood? (*d*) sapwood? (*e*) pore? (*f*) resin duct? (*g*) springwood? (*h*) summerwood? (*i*) vessel?

(9) How does the amount of moisture in a piece of wood vary if the wood be taken from a place where the air is dry and placed where the air is moist?

(10) Find the freight charge, at 17 cents per hundred pounds on a car containing 16 cords of white spruce, averaging 92 cu. ft. of solid wood and moisture content equal to 90% of the oven-dry weight. Ans. $105.28.

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(11) What are the important chemical constituents of pulpwoods?

(12) Why is paper that was made centuries ago still in good condition?

(13) What occurs when wood is cooked in a pulp mill?

(14) What substances in wood are converted into sugars by hydrolysis?

(15) Why is wood resin troublesome in the paper mill?

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SECTION 2

PREPARATION OF PULPWOOD

By S. ROY TURNER, B.Sc.

INTRODUCTION

1. Delivering Wood to Mill.—This Section deals with the handling and preparation of pulpwood from the time it reaches the mill until it is turned over as blocks, for the manufacture of mechanical pulp, or as chips, for the manufacture of chemical pulps.

Wood may be delivered to the mill in any one of the following ways:

(*a*) Long logs, from 8 feet upwards in length, which have been cut in lumber camps and floated long distances to the mill.

(*b*) Logs formed into rafts on the ocean, the large lakes, large rivers, etc.

(*c*) "Farmers' wood," which is usually 4 ft. long and is either peeled or unbarked. This class of wood is cut by farmers, piled on a steep river bank (if cut near a mill) until high water comes, then pushed into the river, and floated to the mill. See (*e*) below.

(*d*) Long unbarked logs, similar to class (*a*), piled about 9 feet high on flat cars and delivered at the mill siding, where the side braces are cut and the logs skidded (slid) into the mill pond or stored in piles in the mill yard, to be used as required.

(*e*) Short wood, termed "car wood," from 24 to 48 inches long, depending on the mill requirements, barked or unbarked, and delivered on cars at the mill siding. Farmers' and settlers' wood is usually delivered by them along a railway; it is then shipped by rail to the mill.

(*f*) Wood, usually in 4-foot lengths, frequently barked by dealers and delivered to barges, schooners, or steamers.

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2. Measurement of Pulpwood.—The solid volume in a standard cord is assumed to be 95 cubic feet, although it actually may vary from 88 to 95 cubic feet, depending on the length and diameter of the wood, number of crooks, knots, etc., and whether it is rough or barked. Accordingly, the actual solid volume in a cord may be from 66% to 74% of the volume of a standard cord of 128 cubic feet. When calculated from the board feet in timber, as estimated by the various log rules, a cord is generally assumed to be equivalent to 500 board feet.

Green spruce weighs around 4,300 pounds per cord, while green balsam weighs around 4,500 pounds. Dry peeled wood weighs about 3,300–3,500 pounds. The moisture does not of course change the amount of fiber in the wood. The weight varies, however, with the season in which the wood is cut, the length of time in storage, etc., since these factors change the moisture content, but do not, of course, change the amount of fiber in the wood. However, the weight and quality of the fiber are very seriously affected by fungi, and the fiber is often completely destroyed, leaving only a mass of punk. There is a present day tendency to buy wood by weight of dry fiber, and considerable progress is being made in this direction. While this requires sampling and testing for moisture, it is far more sensible than the common practice of buying by volume, which may be made up of fiber, punk, or air.

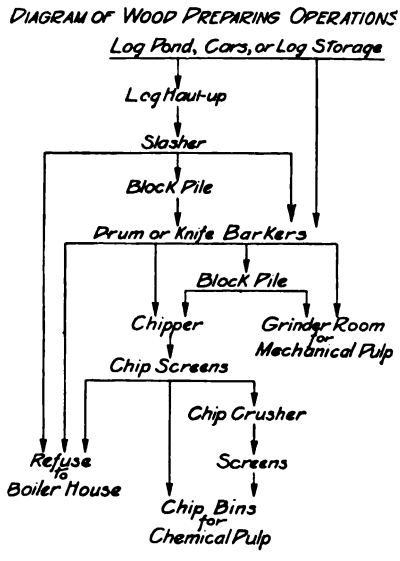

Fig. 1.

When wood is bought in log lengths, the diameter and length are measured, and the contents in board feet (1 board foot is 1 ft. long, 1 ft. wide, and 1 in. thick and equals $1\frac{1}{2}$th of a cubic foot) is found by means of tables computed for that purpose. Or the contents in board feet is found by one of the several "log rules;" this may be converted into cords by multiplying the number of

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thousands of board feet so found by 2. Thus, if the result obtained is 17,250 feet (board feet), the number of cords of unbarked wood required to make this is $17.25 \times 2 = 34.5 = 34\frac{1}{2}$ cords. In other words, a standard cord, $4' \times 4' \times 8'$, is generally considered to be equivalent to 500 feet, board measure; as calculated for rough logs.

3. Diagram of Wood Preparing Operations.—The diagram, Fig. 1, shows very clearly the course of the wood from the log in the pond or storage to the grinder room or the chip bin. This diagram will be appreciated better after the reader has finished studying this section, and he will do well to study it then.

THE CUT-UP MILL

4. General Arrangement.—The general arrangement of a **cut-up mill** usually includes a log haul-up, or jack ladder, a slasher, a system of conveyors (for conveying the cut logs, as wanted, and the refuse to the boiler room), and the driving element, which may be a motor, a steam engine, or a hydraulic turbine.

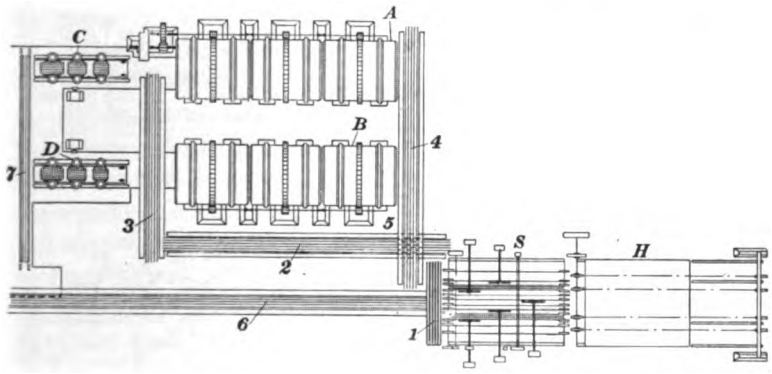

FIG. 2.

5. In Fig. 2 is shown a very well laid out cut-up mill; it includes one parallel log haul-up, one five-saw slasher, two barking drums, two bark presses, and a system of conveyors to carry the blocks through the process.

The logs are hauled from the river by means of a four-strand parallel log haul-up *H*, slashed into blocks (usually 2 ft. or 4 ft. long) on the 5-saw slasher *S*, and automatically discharged into conveyor 1, carried to conveyor 2, and thence to conveyor 3,

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which distributes the blocks between the barking drums *A* and *B*. The blocks are discharged from the drums onto conveyor 4. A man is stationed at 5 to haul poorly barked blocks off conveyor 4 and on conveyor 2, which allows them to go through the drums again. The barked blocks continue along on conveyor 4 and are dumped on conveyor 6, to go direct to the wood room or storage pile. The bark that is discharged from the drums drops to a conveyor located beneath them and, in the ideal plant, is carried to the bark presses *C* and *D*, where a large proportion of the water is squeezed out of the bark, to fit it for use as fuel. After being pressed, the bark is discharged on conveyor 7, which takes it to the boiler house, where it is burned in a special furnace, provided with a large combustion space, called a Dutch oven.

LOG HAUL-UPS

6. Parallel Log Haul-Ups.—The most economical method of hauling logs up from the river to the slasher is by means of a

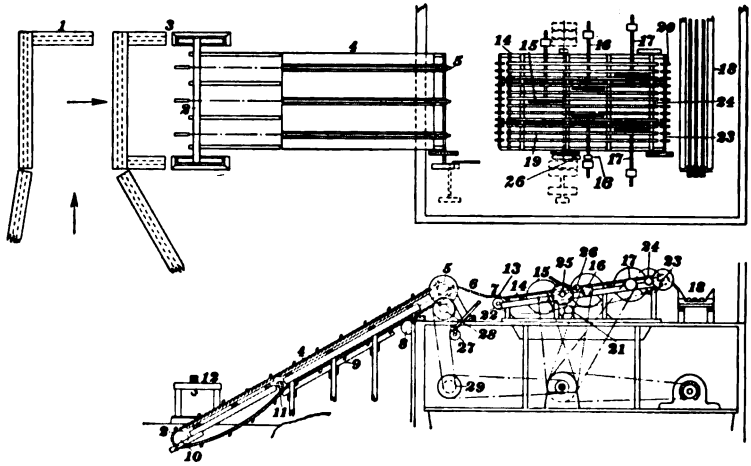

FIG. 3.

parallel log haul-up, such as is shown in Fig. 3. The logs are driven end first into the *boom* (a pocket formed by floating logs, end touching end), in the direction indicated by the arrow, until they bump on the boom stick 1, when they are moved sideways toward 2. At point 3, the boom is left open, and a man pulls

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out to one side the logs that are too large to pass through the slasher and the logs that are better suited to being sawed into lumber. The pulpwood logs are fed to the haul-up; and when the logs have reached the inclined deck at 2, the wing links (see Fig. 6) of two or more submerged parallel, endless chains come up through the water and engage the logs. The chains convey the logs up the inclined deck 4 at a speed of about 70 to 80 ft. per min.; and when they reach the summit or driving end 5, the logs leave the chains, roll down the inclined plane 6 to table 7. Here they all have one end butted against a stop, to insure that the blocks are of uniform length after the logs pass through the slasher.

The logs as they pass the log-haul are recorded as to marking, length, and diameter by one or more cullers, inspectors, or checkers. Thus a record is obtained of the amount of wood reaching the mill. Where there are several companies driving in the same river, and the driving is done by a logging association, the association generally provides one of the cullers. At the end of the season a settlement is then made for any logs belonging to another company, based on the cullers' tally-sheet.

7. The Chains.—As they travel up the deck of the log haul-up, the chains ride on steel wearing strips between hardwood guides until they reach the drive sprockets 5, Fig. 3; here they discharge the wood as previously described, pass through the deck, around the drive sprockets, and engage with the idler sprockets 8; they then slide down the steel-shod chain guides 9, around the flanged tail sprockets 10, and up the inclined plane again.

These chains are made of short pieces of steel bars (links), riveted together, and have cast-steel lugs, or wing links, Fig. 6, that are 6, 8, or 10 inches high and spaced approximately 54 inches apart, center to center, the entire length of the chain. It is the duty of these wing links to engage the logs as the chains advance under them and approach the surface of the water. The wing links on each side of the chains emerge from the water at the same time, and the logs are carried up the deck in a horizontal position, at right angle to the direction of motion of the chains. The height of the wing links varies, on account of the average size (diameter) of the logs used in one mill being quite different from that used in another mill, and also on account of the different inclinations of the log haul-ups at different mills.

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8. Raising and Lowering End of Haul-Up.—Fig. 3 also shows the hinged joint 11 of the inclined deck and the towers 12. A beam spans the towers; and when it is required to raise or lower the end of the log haul-up, to allow for variations in the elevation of the water or for repairs, chain blocks are slung on the beam for this purpose, and the tail sprockets are adjusted as desired. A cable then supports the adjusted end of the log haul-up, and the chain blocks can be removed. This provision is necessary in winter weather.

9. Power Required for Haul-Up.—The angle of inclination of this class of haul-up (angle which plane makes with horizontal) is usually between 30° and 40°. The power required to operate the haul-up is easily found when the pull on the chains and the speed at which they travel is known. Thus,

Let P = total pull of chains, in pounds;
V = velocity of chains in feet per minute;
W = total weight of chains and logs on the deck;
μ = coefficient of friction
f = factor of safety
ϕ = angle of inclination
HP = horsepower

Then,

$$HP = \frac{PVf}{33000} \qquad (1)$$

The coefficient of friction may be usually taken as .3 and the factor of safety as 2. Then, for horizontal conveyors, $\phi = 0$, $P = .3W$, and

$$HP = \frac{.3WV \times 2}{33000} = \frac{WV}{55000} \qquad (2)$$

For inclined conveyors,

$$P = W(\mu \cos \phi + \sin \phi),$$

and

$$HP = \frac{WV(\mu \cos \phi + \sin \phi) \times 2}{33000} = \frac{WV(\mu \cos \phi + \sin \phi)}{16500} \qquad (3)$$

If the reader is unfamiliar with the use of trigonometrical tables, he may use the following formula for P, which is the same as that given in Art. **156** of *Mechanics and Hydraulics*, §1, Vol. II, except that the minus sign has been changed to +, because the direction of motion is *up* the plane in this case. Here $P = f'$,

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$W = P$, l = length of plane, and h = height of plane; then,

$$P = \frac{W}{l}(h + \mu\sqrt{l^2 - h^2})$$

Substituting this value of P in formula (1), .3 for μ, and 2 for f,

$$HP = \frac{WV(h + .3\sqrt{l^2 - h^2})}{16500l} \qquad (4)$$

The reason for changing the sign from $-$ to $+$ should be evident. In the former case, it is desired to find the component of gravity acting parallel to the plane that pulls the body *down* the plane, and this is *less* by the amount of the friction; in the present case, the body is pulled *up* the plane, and the component is *increased* by the amount of the friction.

10. Single-Strand Log Haul-Up.—By reason of the location of some cut-up mills relative to the boom from which the logs are drawn, another type of log haul-up is used; it is called a **single-strand log haul-up** and is shown in Fig. 4. Logs are hauled up,

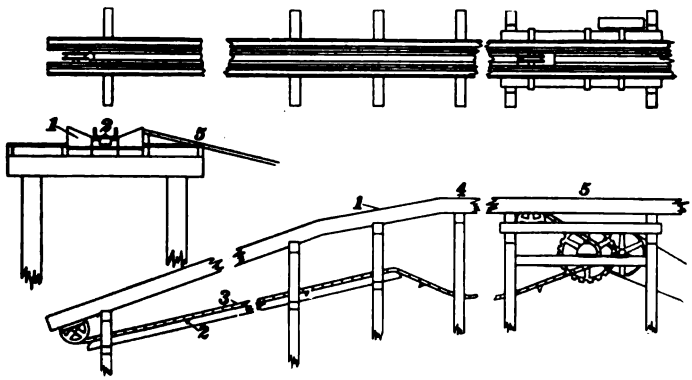

Fig. 4.

end on, in a V-shaped, steel-lined trough 1 by means of flights (lugs) on a cable (see Fig. 20) or by spurs 2 on a single-strand conveyor chain 3, having a speed of about 250 ft. per min.; the logs are discharged at the top of the incline 4 on the deck 5. Here two quick-acting kicker arms, which are operated by steam or compressed-air cylinders below the floor and are controlled by an operator who commands a view of the whole sawing table, rise through the deck behind the log and roll it down the inclined plane and on the slasher chains; the kicker arms disappear through the deck, and the log is then butted, straightened, and

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carried to the saws on slasher chains, as described in Art. **6.** In some mills, the logs are discharged from the conveyor automatically, by gravity, without using the kicker arms.

A log haul-up of this type is not as efficient as the parallel continuous-chain type described in connection with Fig. 3; it is seldom seen, its use being entirely confined to mills in which logs cannot be brought up to the slasher parallel to one another or where logs are more than two feet in diameter. This type of haul-up is also used on swing-saw installations. See Art. **12.**

In British Columbia, where the logs often measure 6 ft. in diameter, they must first be sawed in the same manner as for timber, and the timber conveyed to the slasher: here the single-strand conveyor is required. The log is first rolled upon a saw-mill carriage.

11. European Practice.—In Europe, and in a few mills in America, the logs are bunched into slings before they leave the water; afterwards, they are hoisted out of the water and piled in long regular piles, about 12 ft. high, before being slashed, barked, and brought to the mill. Logs that have been regularly piled this way permit the free passage of air between the logs, and the wood contains considerably less moisture after being chipped than when wood is slashed, barked, and piled in ordinary storage piles. It is better practice to bark the wood before storing, however, since the wet wood is barked more easily; the barked wood dries better, and it is less subject to rot and to insect and mold attack.

12. Swing Saws.—When a mill is receiving only a small percentage of logs that are too long for the slasher to cut, it is advisable to install a **swing-saw system,** such as is shown in Fig. 5, to cut the logs into blocks of the required length.

The logs are hauled from the mill pond by means of a single-strand log haul-up, as described in Art. **10** and shown in Fig. 4. As the log passes the summit of the incline, the chain is stopped, the log is rolled out of the trough and down the inclined deck 1 by means of the kicker arms 2, which are operated by steam or air cylinders below the deck. These kicker arms are plungers or levers, and they push the log out of the conveyor to the log deck. When the log reaches the loader arms 3, it is held, and is only released when required to be rolled on the feed rolls 4. The feed rolls, which are operated by means of a lever and friction

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pulley drive, carry the log against the log stop 5; the feed rolls are then stopped, the log stop is dropped by operating a foot pedal, and the revolving saw 6 is lowered by means of a lever and steam- or air-cylinder arrangement to the log, which is then cut to the correct length and dumped into the conveyor 7. The log stop and saw are then raised, the feed rolls are revolved, and the log is carried against the log stop. These operations continue

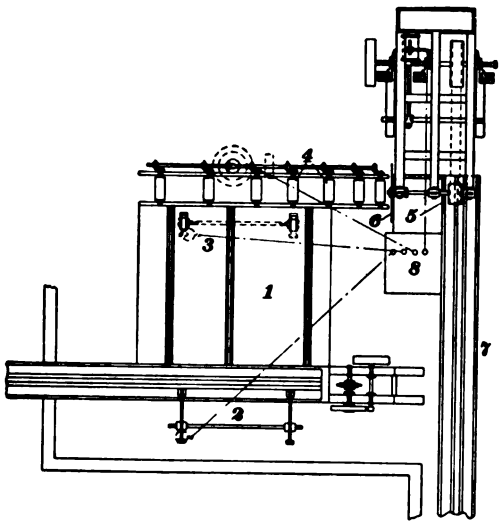

FIG. 5.

until the log is completely cut up into blocks. The entire operating mechanism is controlled by the sawyer, who stands on platform 8, from where he can oversee all operations.

About 25 horsepower is sufficient to operate an arrangement of this kind.

SLASHERS

13. Kind of Work Done by Slashers.—A **slasher** is a machine built as illustrated in Fig. 3; to cut logs into any predetermined length. The logs are picked up by endless feed-chains that run at 30–40 ft. per min., which form a cradle for holding the logs, and which carry them up an inclined plane and against 60-inch diameter circular saws that revolve at 750 r.p.m. The saws cut the logs into two or more pieces of the desired length. After the

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pieces (blocks) are clear of the saws, they are automatically discharged into a conveyor that runs at right angles to the direction of the slasher chains, and are conveyed to the barking drum or to the storage pile.

Slashers may be built on the concrete floor of a cut-up mill (also called the *saw deck*), the machinery being supported by steelwork in the floor; or they may be built, as is usually done, with the machinery supported on wooden bents, which are assembled on the floor of the cut-up mill and rigidly braced together.

14. Description of Slasher.—Referring to Fig. 3, assume that the logs are 12 ft. long and that they are to be cut into six equal lengths; there will, therefore, be required 12 feed chains, 2 chains for each block when cut to length.

When the logs roll on the table 7, the ends are butted, and the 12 parallel continuous feed chains, coming through the table at 13, pick up one or more logs, convey them at a speed of about 30 ft. per min. up the sawing table 14 (which may be horizontal or slightly inclined), and carry them against the leading saw 15, which cuts the log into two pieces. After passing this saw, the width of the saw cut is increased to 1½ in. by means of a spreader that is located directly behind the first saw, the object being to prevent cramping when passing through the following saws. At a distance of about 6 ft. from the center line of the first saw (leading saw), the two saws on the second arbors (shafts) 16 cut off the inside ends of the two pieces made by the leading saw 15. After passing through this second line of saws, the pieces are carried through a third line of saws 17, the center line (axis) of whose arbor is located about 6 ft. from the axis of the second line of saws, and the outside pieces are cut in two, thus making 6 pieces (or **blocks,** as they are termed) from the original 12 ft. log, all of equal lengths. It is obvious that saws can be spaced, so as to cut blocks of other lengths. The blocks are now carried over the upper end of the slasher 20 and discharged on conveyor 18.

These 12 continuous feed chains, like the haul-up chains, are constructed of steel bars, the ends of which are joined to one another by side links of the same length, similar to the construction of a bicycle chain. On approximately 20-inch centers, there are inserted, in place of the plain bar link, a special cradle casting, or *spur*, several types of which are shown in Fig. 6. Spurs of this character are also employed on the haul-up chains,

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both on the parallel-chain and single-chain types of haul-up chains. The chains come through the table at 13, Fig. 3, are hauled up the chain troughs 19 to the drive sprockets 20; they pass around these sprockets and under the sawing table, where

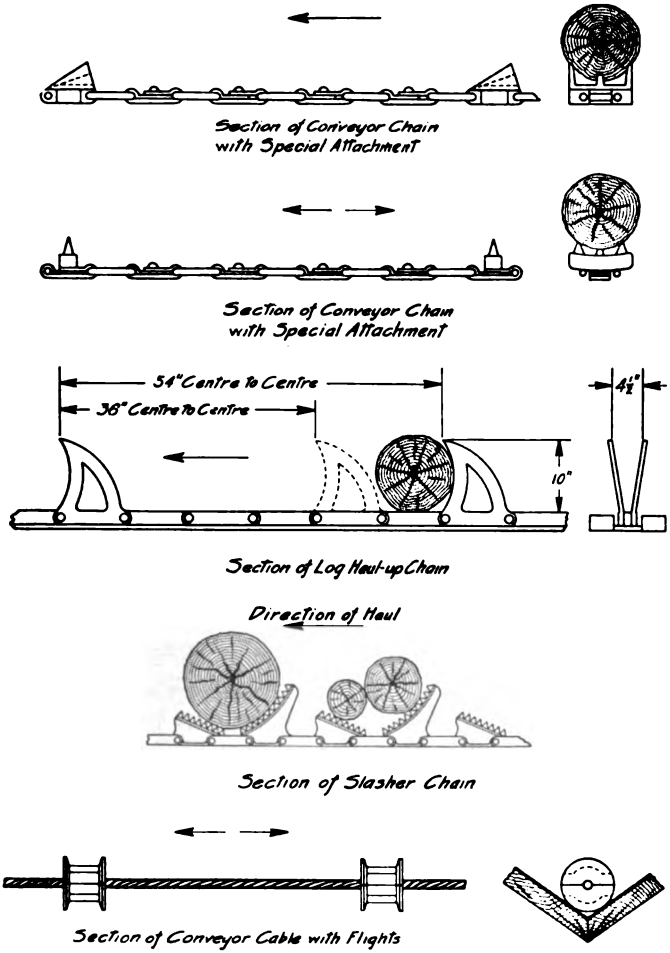
Section of Conveyor Chain with Special Attachment
Section of Conveyor Chain with Special Attachment
54" Centre to Centre
36" Centre to Centre
4½"
10"
Section of Log Haul-up Chain
Direction of Haul
Section of Slasher Chain
Section of Conveyor Cable with Flights

FIG. 6.

they engage with the idler sprockets 21; continuing on below the table, they come around the tail sprockets 22 and up through the table again at 13. The chains are driven by toothed drive sprockets 20 on shaft 23, which is geared to shaft 24. Shaft 24

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is belt driven from shaft 25, which is driven from the second arbor shaft 16 by means of a belt and tightener 26. If, for any reason, it is desired to stop the travel of the load on the sawing table without stopping the saws, the tightener is raised by means of a rope running to the overhead beams and thence to a point near the operator, or by means of a lever attached to a bent of the slasher. Provision should always be made for stopping the travel of the chains on slashers at any time, as logs often get crossed on the sawing table, and time is saved only by stopping the travel of the logs. A log that is too large to be cut through by the saws occasionally gets on the slasher; in such case, the log is sawed part way through (as far as the saw will cut), the feed chains are stopped, and the remainder of the cut is chopped before the stick (log) enters the next saw.

15. Slasher Details.—The arrangement of the saw arbors relative to the feed chains and other parts of the slasher is such that the saws may be removed in a few minutes of time, without removing the arbors from the bearings. Slashers are built for all lengths of logs and to cut any length of blocks. The power required to operate a slasher successfully is 20 h.p. for each 60-inch saw; that is, a 5-saw slasher using 60-inch saws would require $20 \times 5 = 100$ h.p. This gives sufficient power to operate a log haul-up of not more than 4 chains, for a haul of not exceeding 75 feet.

The drive for the slasher is usually from a basement, where a shaft is either direct-connected to a motor or is belt driven from a motor or a steam engine. The log haul-up is generally driven from the same drive shaft. A tightener is placed against the vertical belt 27, Fig. 3, which drives the countershaft 28, the latter being geared to the drive shaft 5. To stop the log haul-up, the tightener is released, and the belt slips on pulley 29. In mills where there is no basement, the drive for the log haul-up and slasher may be arranged to come from overhead instead of from below the floor.

Where it is necessary to cut a short piece off the end of a log to remove rot, a bad end, or to cut to exact length, a trimmer saw is installed at one side of the slasher, usually ahead of the leading saw.

Substantial safety guards should always be provided, in order to protect workmen from injury in case one of the rapidly revolving saws burst or if, for any reason, a block should jump. Low

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hanging screens in front of each saw, made of heavy wire are very satisfactory for this purpose.

BARKING THE WOOD

16. Reason for Barking.—In order to make pulp of good quality, it is necessary to remove the bark from the blocks; this operation is sometimes called *rossing*. Another reason for removing the bark is that the bark has very little, if any, fiber value, and it consumes chemicals and steam in cooking, and takes up valuable space, without yielding a return. Specks of bark make dirty pulp and paper, and it is easier to remove dirt from the wood than to remove it from pulp. Two principal types of apparatus are used; *barking drums; knife barkers.* However, wood is often barked by settlers and farmers with a draw-knife, and poplar is peeled in the woods, while green, by splitting the bark with a long handled chisel, called a spud, and pulling off the bark in long strips.

BARKING DRUMS

17. Types of Barking Drums.—Generally speaking, there are two systems of barking wood in **drums**: the *continuous system* and the *intermittent system.*

The **continuous system** is best adapted to present-day conditions, and is the one most used at the present time. In this system, the wood is fed automatically into one end of the barking drum, where it is tumbled about and automatically discharged at the other end. This system may again be divided into two classes: *tumbling barrels*, of which there are four types and *stationary barkers.*

18. Tumbling-Barrel Types.—Generally speaking, barking drums of this system all work on the same principles, although each of the four types has special features that are made use of in each particular drum, and which are described later. The blocks of wood are conveyed to the upper end of the drum (or drums) and are slid down an intake chute into the drum, in which they are tumbled against one another. This tumbling rubs off the bark, which passes out through narrow slots between the structural sections of which the drum is built, the blocks being

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retained in the drum until they work their way out at the discharge end.

19. The disadvantages of this system are:

(*a*) The ends of the blocks are more or less *broomed;* particles of dirt, some of which cannot be gotten rid of, are driven into the broomed ends; later, these particles appear in the paper, and are always a source of annoyance.

(*b*) Blocks of wood may remain in the drum for a considerable time and may finally be discharged badly slivered; this means a loss of wood.

When blocks of wood not completely barked are discharged from the drum, they are returned to the intake end of the drum by means of a special return conveyor.

The principal advantage of this system is that the bark is quickly and cheaply removed from the block without any great waste of wood, as is the case with the various types of knife barkers.

20. Aids in Removing Bark.—Some of the methods employed to aid in removal of bark from the blocks and in cleaning the wood are the following:

(*a*) Run the drum open, and use sprays at one or both ends of the drum.

(*b*) Do the barking in a dry drum, but have a washing section running in a tank of water at the end of the dry drum, through which all the wood is passed.

(*c*) Revolve the drum and wood in a tank that is partly filled with water, using sweepers fastened to the outside of the drum, to keep the bark from accumulating in the bottom of the tank.

21. First Type of Barking Drum.—The first of the four types of the tumbling-barrel system of barking drums to be considered is illustrated in Fig. 7. This drum is built in three sections, *A*, *B*, and *C*, each 12 ft. in diameter by 15 ft. in length. Each section has its own girth gear *D*, tires *E*, and 4 sets of supporting rollers *F*.

The drum is constructed of heavy channel sections *G*, having the flanges turned out, thus giving a smooth interior, with the exception of the slots between the channels, which allow the bark to pass out. The channels are riveted to the heads *H*, the steel tires *E*, and the girth gear *D*, clearance being allowed between the three drum sections to avoid interference. The com-

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plete drum may be set level or at a slight inclination, say ¼ in. in 12 in., to help reduce end thrust. A retarding ring at the lower end of each section helps to hold the wood in that section for a longer time than would be the case if the ring were not there. An intake apron *K*, discharge apron *L*, and special nozzle sprayers *M* are the remaining outstanding features of this type of drum. It is sometimes necessary to rivet a flat bar to the inside of one of the channel bars *G* in each section; this keeps the wood from sliding instead of tumbling. The drum is driven by pulley *S*, through gear *T* and shaft *U* to gears *V* and *D*.

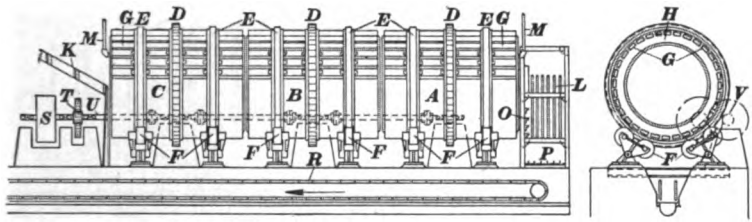

Fig. 7.

The blocks, which may come from the slasher, freight cars, block pile, or from the pond, fall from a conveyor to apron *K*, and thence into the drum. They are pushed forward by more blocks coming in, and they finally tumble out over the gate *O*, against the apron *L*, to the conveyor *P*. The bark falls into the trough below the drum and is carried away by the conveyor *R*. Blocks not cleanly barked are sorted out and sent back, as explained in Art. **5**, and Fig. 2.

The intake and middle sections of this drum run dry; only the discharge-end section is sprayed, to clean the wood.

22. Second Type of Barking Drums.—The second type of the tumbling-barrel system of barking drums is illustrated in Fig. 8. This drum is built in four sections *A*, *B*, *C*, *D*; each section has its own tires *E*, 4 sets of supporting rollers *F*, and each section is revolved separately by means of a girth sprocket *G* and chain *H*, which is driven from a line shaft *K*. The drum has a steel-plate shell, which gives a smooth interior, and slots are cut into the shell, to allow the bark to escape. The shells are riveted to the heads *L*, to the cast-steel tires *E*, and to the girth sprockets *G*, and the shells are all set level. The blocks are fed from conveyor

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M, down slide W, and the unbarked or imperfectly barked blocks are returned by conveyor N.

The barking of the blocks is accomplished in the first three sections, which run dry, and the discharged bark is conveyed direct to the boiler house, by conveyor P, to be used as fuel. The blocks are tumbled from the third into the fourth section, which runs in a tank of water and is set slightly below the other sections; here the blocks are washed and discharged into a conveyor V. Any bark that is removed in the fourth section is run into the sewer.

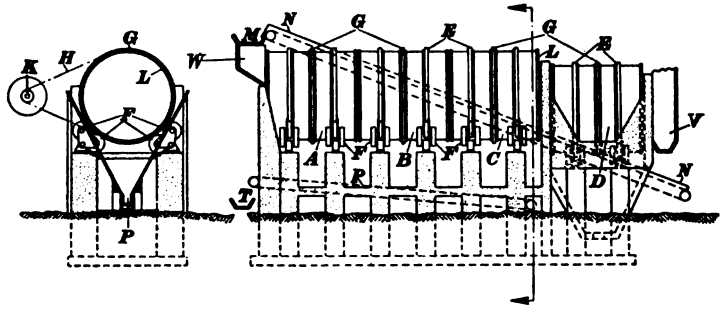

FIG. 8.

23. Third Type of Barking Drums.—This type of the tumbling-barrel system of barking drums is illustrated in Fig. 9; and is a much used type. The drum is built in a single section, and revolves in a tank of water. The blocks enter this drum in a manner similar to that previously described; they are tumbled about inside the drum until they are discharged over the dam sections 1 to conveyor 2.

This drum is suspended in a semi-circular tank of water A, from an overhead structural framework, by means of 4 heavy steel chains K, which run on steel rings B (riveted to the exterior of the drum) and on traction wheels C, which are supported on the overhead framework. Spring take-ups are provided on the traction wheels, to overcome any unequal loading of the carrying chains, and 4 special thrust rollers D take care of any side thrust of the drum. Like the drum shown in Fig. 8, this drum is revolved by means of a steel girth sprocket, riveted to the drum, and by a driving chain F, which is driven by a motor M that is situated on the overhead framework.

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The drum is built of special U-shaped bars *N*, which run the full length of the drum and are assembled in such a manner as to give a corrugated interior surface, which tends to increase the barking action. Spaces are left between the U bars, to allow the bark to pass out. Bands are riveted on the outside of the U bars, to make the drum keep its shape. Sweepers are bolted on the outside of the drum, which carry the bark from the bottom of the tank and discharge it into the trough *H*.

24. Fourth Type of Barking Drums.—This type of the tumbling-barrel system of barking drums is a combination of the drums shown in Figs. 7 and 9. The drum is built of special

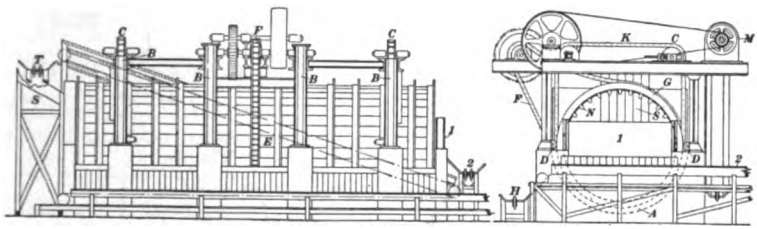

FIG. 9.

corrugated sections (bars), which are held in place to form a circular cylindrical shape, with the bars running parallel to the axis, by means of cast-steel tires, a girth gear, and steel bands, all of which are riveted on the exterior of the drum.

This drum runs in a semi-circular tank of water; it is supported by means of 4 sets of rollers driven by a pinion and girth gear, which are located at the center of the drum.

25. Factors Affecting Capacity of Barking Drums.—Variations in the capacity of barking drums are due to the following conditions:

(*a*) The length of time that the wood has been in the water.

(*b*) The season in which the wood is taken from the water.

(*c*) Whether the logs were driven in streams having rapids or in quiet water.

(*d*) Whether the wood is allowed to stand in piles after being hauled from the water or whether it is taken direct through the slasher to the barking drums.

Although the capacity of barking drums cannot be accurately determined, the following table will give a rough idea of what

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may be expected under the conditions mentioned for the sizes of drums given:

APPROXIMATE CAPACITY OF BARKING DRUMS. CORDS PER HOUR

Barking conditions		Size of drums		
Class of wood	Period in water	8′ × 30′	10′ × 30′	12′ × 45′
Wood driven in quiet water				
Car	Never	4.0	6.5	12.5
River	2 weeks	5.0	7.5	15.0
River	2 months	5.5	10.0	20.0
River	4 months	7.0	12.0	22.0
River	6 months or more	9.0	15.0	25.0
Wood driven in streams having rapids				
River	2 months	7.5	16.0	27.0
River	4 months	12.0	20.0	32.0
River	6 months or more	20.0	25.0	37.0

The treatment the wood gets in the water is a considerable factor; the more barking it gets in shooting rapids, etc., the less work for the barkers.

To obtain the best results from any type of barking drum, namely, the greatest amount of clean wood with the least number of broomed ends, the drum should be run half full of wood. Wood barked in drums having smooth interiors will have less brooming on the ends of the blocks than when there is a projection of some kind on the inside, regardless of whether the projection be angles or corrugated sections.

26. Power Required.—The amount of power required for any type of barking drum depends upon the amount of wood in the drum when the drum is started, and any motor that is installed should be large enough to take care of this starting torque. The motors listed in the following table are sufficiently large to operate drums of the sizes and speeds given.

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POWER REQUIRED FOR BARKING DRUMS

Size of barking drum	Speed (r.p.m.)	Power required
12′ × 45′ (3 sections).....	6.0	150 h.p.
10′ × 30′ (1 section).....	7.5	75 h.p.
8′ × 30′ (1 section).....	9.0	50 h.p.

In both of the above tables, the first dimension given in specifying the size of the drums is the diameter and the second dimension is the length.

STATIONARY BARKERS

27. Description of Stationary Barkers.—The latest type of barker to be developed is illustrated in Fig. 10. The logs are taken from the log haul-up, sorted into three sizes (large, medium,

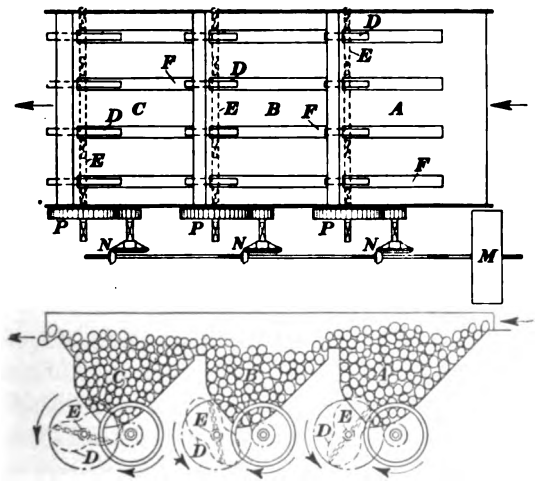

FIG. 10.

and small), and each size is continuously fed in the direction indicated by the arrow to a set of three pockets *A*, *B*, *C*. Revolving at the bottom of each pocket are 4 double-ended cams *D* (for 16-foot logs), which are located in line on shafts *E*, which revolve at 15 r.p.m. The cams, which are approximately 6 ft. over all and have a 6-inch face, lift the logs and give them a

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rolling motion in the pocket at a rate depending on how fast the logs are fed into the first pocket *A*. The well-barked logs, when discharged from the third pocket *C*, are conveyed either direct to the slasher, which, for chemical pulp, cuts them into 8-foot lengths, or they are conveyed to the storage yard, where they are piled and allowed to dry; all unbarked logs are returned by means of a conveyor to the first pocket to be re-barked. A water spray, playing on top of the wood in each pocket, keeps the bark wet and aids in its removal. The bark drops to the bottom of each pocket as it leaves the logs, and passes out of the drum through the slots *F* in which the cams work.

Each barker is belt driven from a 175-horsepower motor, which connects to a pulley *M* on the main-line shaft; from this shaft, each cam shaft is driven at reduced speed by means of bevel and spur gears *N* and *P*. What may be called the center lines of the cams are set 60° apart, in order to give a more uniform torque on the motor.

The maximum capacity of this barker has not been determined, but the manufacturers claim it will bark 18 cords of wood per hour.

28. Advantages of Stationary Barkers.—The advantages claimed for this type of barker are:

(*a*) A considerable reduction in the waste of wood over that barked, as formerly, on a knife barker.

(*b*) A clean block, 8 ft. long, free from dirt specks or broomed ends; and when chipped, the chips will have fewer long slivers and sawdust than when shorter blocks are used.

(*c*) A further saving is obtained by reason of slashing the log only once; this means that instead of great quantities of saw dust, which can be used only for fuel, the loss in saw dust is replaced with chips. Further, only one slasher saw is required.

(*d*) The barked logs can be piled in the open air; this results in better chips and, consequently, better pulp.

A possible disadvantage is the chance for splintering the outer layers of the wood through the rubbing action of the cams

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INTERMITTENT BARKING DRUMS

29. Description and Operation.—The original barking drum of this type is shown in Fig. 11. The unbarked wood is stored in a hopper *A*, which is directly over the drum *B*; and when it is

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desired to fill the drum, the side door *C* of the drum is turned up and the door thrown open. The hopper doors are opened by the chain and gear *H*, to allow the wood to drop into the open drum, and they are closed when the amount of wood required to fill the drum has been taken out. The door of the drum is now bolted down, and the drum is revolved at the rate of 10 r.p.m. While the drum is revolving, water is constantly flowing into the drum through the hollow journal at one end *E*, and the bark (which has been separated from the wood inside the drum) goes

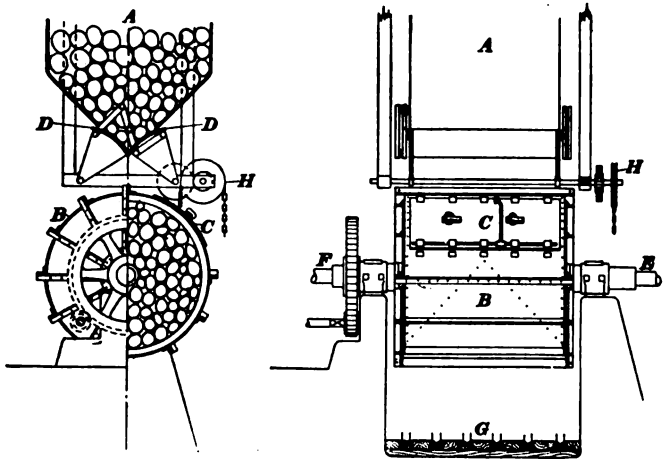

FIG. 11.

out with the dirty water at the other end *F* through the hollow journal. After the wood has been in the drum a length of time sufficient to remove the bark, the drum is stopped, with the door side up, the door is unbolted, and the drum is turned 180° (half a revolution), so that the opening is down; the wood then falls through the open doorway and to the conveyor *G* below, where it is washed and carried away to the chippers.

A drum of this type is particularly well adapted to barking blocks of wood or saw-mill slabs up to 8 ft. in length, these being neatly piled in the drum. On round pulpwood, it has a capacity of from 24 to 40 cords per 24 hours. About 30 h.p. is required to operate it when under full load. The body of the drum is approximately 9 ft. 6 in. diameter by 9 ft. in length; it is built of steel plates, bent and riveted to semi-steel heads, on which hollow journals are cast, which support the drum. Projecting angles inside the drum help to tumble the wood.

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30. Other drums of this type are built of angle irons or channel irons, which are fastened to circular heads and bands; the bark falls through the openings between these. Water may be sprayed on the drum to wash off dirt and bark from the wood.

When selecting barking equipment, it is important to consider these factors, in addition to the first cost of installation: kind of wood to be cleaned; loss of wood substances; capacity; operating cost; cost of maintenance.

BARK PRESSES

31. Purpose of Pressing Bark.—That there may be as little waste as possible about the mill, the bark discharged from the barking drums that operate on wet wood, should be put through a **bark press,** to squeeze the water out of the bark; this will fit it for burning economically in the boiler house, to which all wood refuse is conveyed (or trucked) and in which it is burned to generate steam. Wood waste requires that boilers be equipped with a large fire space, generally called a **Dutch oven.** It will be seen from the following figures that the amount of fuel derived from the bark from barking drums amounts to a considerable item in a month's time:

A cord of green spruce that contains 45% moisture will weigh approximately 4500 lb.; the bark on this wood represents about 12% of this weight, or 540 lb. of bark, 45% dry, per cord of wood used. Bark coming from the bark presses usually contains 50% moisture, the increase being due to the additional water taken up in the barking drums. Increasing the moisture content of the bark from 45% to 50% will increase the weight of the bark from a cord of green spruce to 594 lb. From a sulphite mill of 75 tons daily capacity and requiring 150 cords of spruce, there would be obtained $\frac{594 \times 150}{2{,}000} = 44.55$ tons of wet bark per day. If the barking drums are operated 26 days per month, the output of bark for such a plant is $44.55 \times 26 = 1158.3$ tons of bark per month. It may now be assumed that 12 tons of bark have the same fuel value as 1 ton of coal; therefore, by installing a bark press and burning the bark in a suitable Dutch oven, the fuel value of the bark is equivalent to $1158.3 \div 12 = 96.50$ tons of coal per month, which is the amount saved by a plant using 75 cords of spruce per day.

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In many cases, the bark is reasonably dry and does not need pressing; in other cases, the bark is burned wet, the heat derived from burning a part of it serving to dry the remaining part. Other wood waste, as chipper sawdust, is also an important factor.

32. Description of Bark Presses.—The patented bark press illustrated in Fig. 12 gives very satisfactory results. The bark, which contains from 60% to 80% moisture is conveyed from the barking drums to the bark press and loaded on the endless chain 1, which carries the bark between the three presses. The pressed

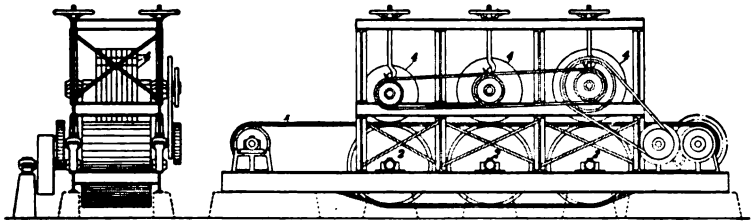

FIG. 12.

bark is discharged into a conveyor at the driving end of the bark press, approximately 50% dry; but this figure may vary, depending upon the dryness of the bark delivered to the press. The bark is then conveyed with the mill refuse from the slasher, together, usually, with the refuse from the chip screens, to the Dutch oven, where it is burned without the addition of other fuel.

The chain on which the wet bark is deposited is made up of flat sections of steel bars, which run at right angles to the directions of the chains; they have a special section of chain riveted to the ends of each bar. The bottom side of the flats comes in contact with the outside of the drums 2, while the bark on the top side of the flat is pressed by the disks 4. On each top shaft, there are 8 disks; each is bored large enough to allow any one disk to rise sufficiently high to permit a knot or other very hard substance to pass through without causing all the disks on that shaft to rise a like distance. Thus only a small proportion of the bark passing through is affected by the entrance of some hard substance. As will be seen in the illustration, the pressure on the bark due to the weight of the larger disks, gradually increases as the bark travels along the chain toward the driving end. Handwheels on

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the top of the structural steel framework permit the operator to raise the disk shafts.

One press of the above type, equipped with a 15-h.p. motor is capable of pressing the bark from 400 cords of wood daily, as it comes from the barking drums.

33. Another press that works on somewhat the same principle is shown in Fig. 13. The wet bark is deposited on the endless chain at *A*, the bark is given one pressing, and is then discharged at *H* to a conveyor that carries it to the boiler house. The chain

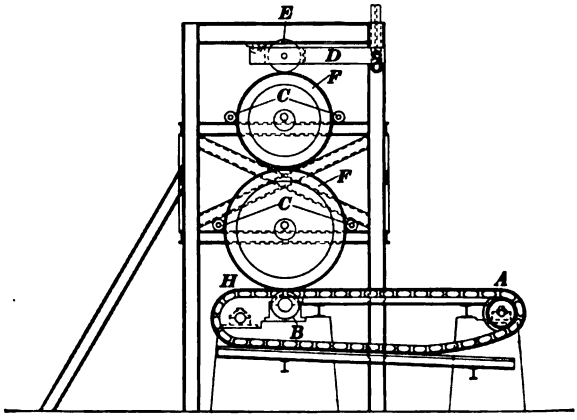

FIG. 13.

on which the bark is conveyed is somewhat similar to that described in the last article. The under side of the flats runs on the solid steel roll *B*, the bark on the upper side being pressed by the weight of the disks *F* above. These disks, which are stacked one on top of the other, are bored large in the center and are guided in a vertical position by the guide rolls *C*. This arrangement allows a considerable weight to be placed on the bark to get rid of the water, and it still enables the disks to rise when very hard substances, such as knots, come along the chain. If it is desired to use a greater weight, the levers *D* are loaded, and a much greater pressure can be put on the bark by means of the roller *E*.

The chain of this bark press runs at 27 ft. per min., and the press is said to be capable of pressing to 60% dry the bark from barking drums that have a daily capacity of 400 cords.

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34. A third type of bark press is shown in Fig. 14. Here the bark is deposited on several strands of ordinary chain-grate stoker chain *A*, which run parallel to one another and are carried between the two presses, where a considerable amount of water is squeezed out of the bark. After being squeezed, the bark is carried onward and dropped over the end on a conveyor, which transports it to the boiler house. The bottom drum *B* of each press runs in fixed journals and is smooth on the outside; but the two top drums *C* are corrugated on the outside, the corrugations running parallel to the axis of the drum. Additional pressure can be secured by increasing the weights on the arms *B*.

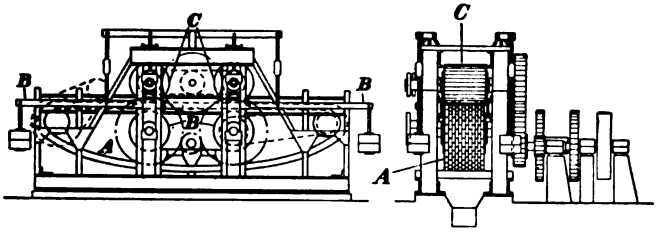

FIG. 14.

The disadvantage of this type of bark press is that if a knot or other hard substance get on the chain, the whole top roll will rise and thus give a strip of unpressed bark across the entire face of the chains. With the disk type of press, on the contrary, the only bark not pressed is that part around the hard substance, and the length of the strip is only equal to the width of the face of one disk.

In order that it may burn more freely, it is quite customary to mix a small quantity of coal with the bark coming from the bark presses of this type.

WOOD STORAGE AND CONVEYING

CONVEYORS

STORAGE-PILE CONVEYORS

35. How Blocks Reach the Storage Pile.—When blocks are discharged from the slasher or from the barking drums (if they are first barked), they are usually transported to the storage pile

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by means of an endless **conveyor** cable that has on it flights or buttons, which are equally spaced at such distances apart as to accommodate the length of the blocks. The blocks, cable, and flights run in a steel-shod conveyor trough, into which a small quantity of water is continuously run, to reduce the friction between the flights and the steel plates. It is customary to have a horizontal, or nearly horizontal, conveyor from the slasher or barking drum to the foot of the inclined conveyor, and the latter may be any one of the three popular types now to be described.

36. Trestle Type of Conveyor.—A block pile conveyor of the **trestle type** is shown in Fig. 15. An endless chain passes around a large gap wheel at *A* and up the inclined end of the conveyor.

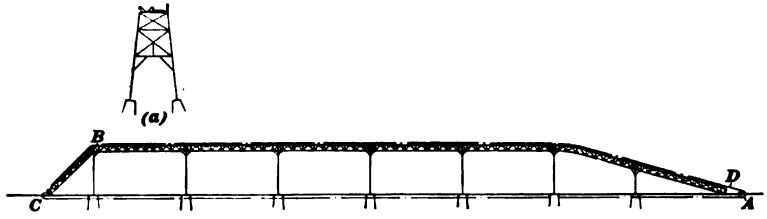

FIG. 15.

The blocks are dropped on the conveyor at *D* and are elevated to a height of 50 ft. or so by the conveyor. After reaching the highest point, they are carried horizontally to the point where it is desired to discharge the blocks from the conveyor. When the cable reaches *B*, it then goes down the incline *BC*, around the tightener and gap wheels *C*, thence through a tunnel under the conveyor, and back again to the loading end. The trestle supports are approximately 125 ft. apart. At (*a*), Fig. 15, is shown one of the supporting frames, with block trough, side walk, and handrail. In Figs. 6 and 20 are shown typical troughs, sections of the sides of which can be removed for the purpose of dropping off the blocks. Several forms of lugs, as used on cables, are shown in Fig. 20, Art. **42.**

The discharging of the blocks is accomplished automatically by leaving the conveyor side open at the point where the blocks should be dropped. After a large number of blocks have been dropped the entire length of the conveyor, and the pile has reached the angle of repose for these blocks (the angle at which the blocks will no longer roll down), which is an angle of about

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39° with the horizontal, portable sections of wooden chutes are laid on top of the pile. These chutes cause less obstruction to the blocks than if they were discharged on the rough pile, and by this means, the blocks are distributed over a very large area. In the case of the conveyor here shown, the blocks were thus distributed to a distance of 225 ft. from the center line of the conveyor.

The return cable runs in a tunnel, the bottom of which forms a return conveyor for bringing the wood back to the mill for use; the sides may be built permanent or by carefully piling wood to a height of 4 or 5 ft.; the top is made by laying pulpwood, which is removed to uncover the conveyor as the wood is used up.

37. Suspension Type of Conveyor.—The **suspension type** of storage-pile conveyor is shown in Fig. 16. The wood starts at A,

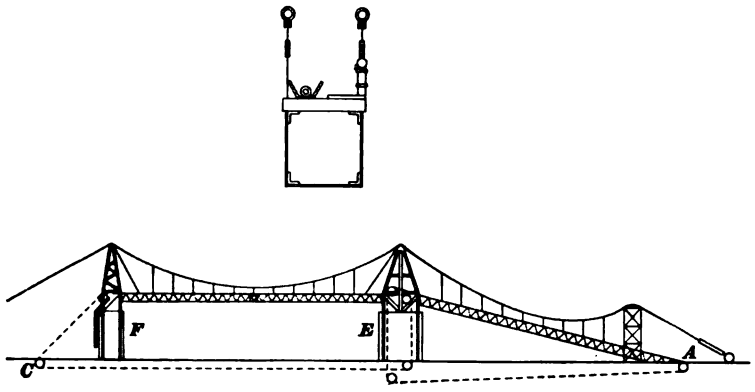

FIG. 16.

and is elevated and distributed in a manner similar to that already described. This conveyor, however, has an advantage in that in all the space between the piers E and F, wood can be stored; moreover, while the area under the inclined section is being piled with wood, only the first cable requires to be operated, which results in less power being used than with the conveyor previously described. The horizontal distance between the supports may be as great as 600 ft. in conveyors of this type.

38. Standard Stacker.—In Fig. 17 is illustrated a **standard stacker.** The wood is transported by a horizontal conveyor to the stacker, and the blocks are then carried up the stacker by a chain or cable conveyor, similar to those described previ-

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ously, to be dropped over the end *B* to the pile below. As the pile increases in height, portable chutes are used, operated as in previous cases, and the width of the pile is thereby extended. When it becomes impossible to discharge any more wood, that is, when the available working area is completely covered to the desired depth, the stacker is moved along a track that runs lengthways of the pile; in this manner, a great pile of wood can be stored at small expense. To keep the overhanging truss of the stacker from tipping over on the storage pile, the opposite end of

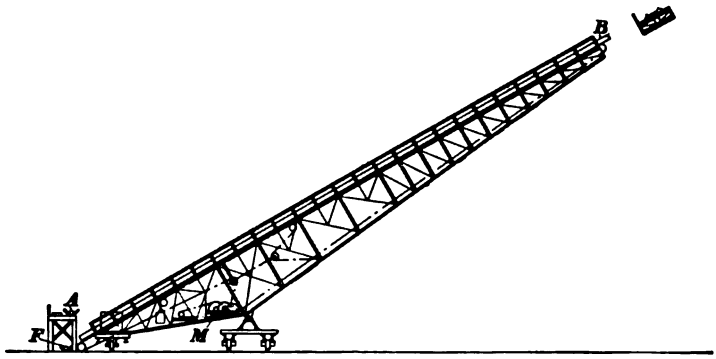

FIG. 17.

the stacker may be loaded with worn-out grinder stones or with concrete blocks. A track the full length of the storage pile, on which to run the stacker, is always necessary.

For a 70-foot stacker, it is advisible to use a 50-h.p. motor to operate it; for a 90-foot stacker, a 60-h.p. motor should be installed; and for a 125-foot stacker, a 75-h.p. motor is necessary.

CROSS CONVEYORS

39. Supplying Wood Room from Storage Pile.—When the cut-up mill closes for the season, it is necessary to take wood from the storage pile to supply the mill requirements. Referring to the storage-pile conveyors shown in Figs. 15 and 16, the return tunnel at the end of the pile *farthest* from the mill is uncovered, and **cross conveyors,** which extend the entire *width* of the pile, transport the blocks to the open tunnel, which is further uncovered as the pile is drawn upon to supply mill requirements. The reason for starting at the end of the storage pile farthest

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from the mill is, if the conveyor should get out of order, the blocks would then require to be *hauled* to the wood room, and the difference in the cost of hauling from the near and far ends of the storage pile amounts to a considerable item. It is also easier to begin piling new wood at the far end, while wood from the near end is being taken to the wood room. Referring to Fig. 16, a considerable saving in power is obtained by first using up the wood between the towers E and F; after which, the conveyor cable that operates in this section can be shut down. This procedure is often reversed, however, one important reason being that the oldest wood should be used first. A special case, too, is where the wood pile is between the pulp mill and the cut-up mill. A separate conveyor is then required, or the piling cable is reversed.

40. Portable Cross Conveyor.—To convey the blocks to the wood room (where a stacker is used), a **portable cross conveyor** is employed to deliver the blocks to a main conveyor, which is located back of the stacker. This main conveyor is also used to supply wood to the stacker during the time the storage is being built up. At such time, a side section of the main conveyor is removed, to allow the blocks to be dropped on the conveyor running up the inclined stacker. During winter, the moisture in the blocks freezes, causing the blocks to stick together, and in most mills, dynamite has frequently to be used to break down the pile, so the blocks can be carried in the portable cross conveyors. Although blasting is very dangerous, yet it is to be preferred to having men go on top of a pile, to break down the blocks, or to having men undermine a pile. Cross conveyors are also used to distribute wood on very large piles.

A very good arrangement for keeping the portable cross conveyors supplied with blocks at the least risk of life is shown in Fig. 18. The cable A carrying anchor E, runs over pulley block F (attached to the conveyor frame), over pulley block H (near the foot of the pile), and is wound in either direction on the motor-driven drum K, which is preferably situated on a high bank. Otherwise, the cable should pass over a high pulley, in order to keep the anchor well up on the pile. The reversing motor is geared to two cable drums; it causes the heavy anchor E to be drawn back and forth across the working face of the storage pile and pulls down the wood from the top of the pile. With a device of this kind, dynamiting is unnecessary, and men

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engaged in loading the conveyors seem to be laboring under much less strain than those working where dynamite is used.

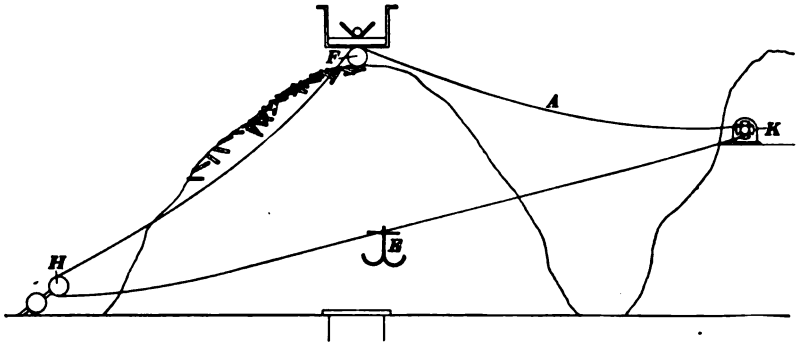

FIG. 18.

41. Pulpwood Reclaimer.—Another apparatus for dragging down wood from the storage pile is shown in Fig. 19. It consists of a carriage *A* running on track *T* along the foot of the pile; it carries the motor *M* and bottom end of beam *E*. At the top of the beam are wheels *W*, which ride on light rails (laid on top of the pile), as the carriage moves along. A chain *F*, driven by a motor-driven sprocket *N*, at the foot of the beam, carries spurs which catch into the blocks on the down journey and drag them down the pile to the conveyor *H*. When a gully has been dug, the carriage is shifted a little. The beam always adjusts itself to the angle of repose of the pile. Except for the occasional necessity of using dynamite in the winter, no man runs the risk of climbing the pile; even then, the beam makes the ascent and descent much safer than usual.

42. Power Required to Operate Conveyors.—Conveyors may be either horizontal or inclined. For horizontal conveyors, the power required by a storage-pile conveyor depends upon weather conditions (wet, frosty, or dry), speed of conveyor, and conditions of the trough (wet or dry). A little water, fed at the top of an inclined, or the beginning of a horizontal, conveyor, makes very good lubrication for the sliding blocks and conveyor flights. Roughly, it requires a 50-h.p. motor to convey blocks at the rate of 40 per minute at a speed of 400 ft. per min. horizontally, or at 225 ft. per min. up an incline. The overload is sometimes as

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much as 50%. A 75-h.p. motor will run the same inclined conveyor, and it will carry 250 blocks per minute.

CONVEYORS IN GENERAL

42. Uses and Shapes of Conveyors.—Conveyors are used in mills wherever it is desired to transport wood from one place to another. Fig. 20 shows a form of bottom section, or shoe, *M* and three ways of attaching the bottom section of the trough to

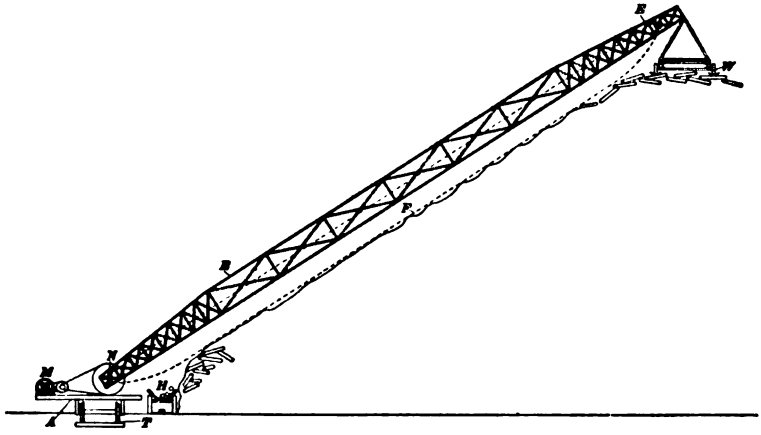

FIG. 19.

the supporting beams. The sloping sides *H* of the trough are usually inclined at an angle of from 35° to 45° with the horizontal, though in some mills troughs are used with sides sloping only 28°. Tests have shown that heavily loaded conveyors consume less power with flat than with steep troughs. Channel or flat iron is generally used to line the trough. Several forms of lugs are shown in Fig. 20.

43. Special-purpose Conveyors.—When the blocks are discharged from the barking drums, some mills use a series of from 4 to 6 parallel chains (close together) as one conveyor, operating at about 30 ft. per min., to transport the wood to the main conveyor that runs to the storage pile. This arrangement allows one man ample time to sort the well-barked from the poorly-barked wood. The well-barked wood is carried to the main conveyor, while the poorly-barked wood is pushed off the chains,

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through an open side in the conveyor trough, and drops on the return conveyor, which feeds it back to the barker.

44. When car wood is received in short lengths, a temporary conveyor is often set up alongside the railway track, to convey the wood from the cars to the main conveyor that leads to the wood room or to the storage pile. Such conveyors may be either horizontal or inclined, depending on conditions at the mill site.

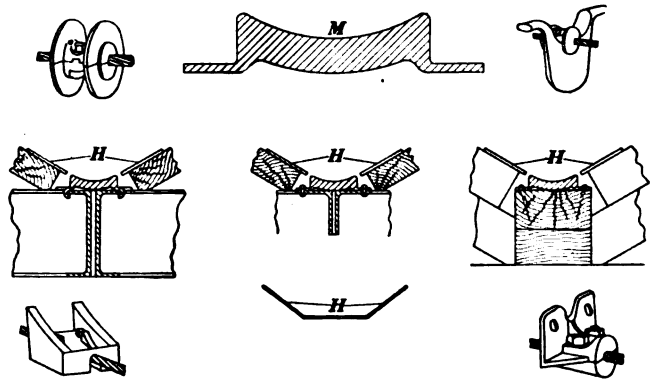

FIG. 20.

45. To convey the wood in the wood-storage pile to the tunnel under the pile, portable sections of cross conveyors are used. This conveyor is generally composed of 12-foot sections of steel-lined trough, in which is a chain, fitted with dog attachments, running in the center. The chain is driven by a small motor, from 15 to 25 h.p., which is belted and geared to a chain sprocket. As the wood in the pile is used, the motor and conveyor sections are shifted up closer to the working face of the pile. The blocks are loaded on the conveyor by men, who take them from the foot of the pile to the conveyor, from whence they are hauled to the end of the portable sections; here they are dropped over the end, and into the tunnel, in which runs the storage-pile conveyor cable.

46. Where a storage-block conveyor, such as is shown in Figs. 15 and 16, is used on a wood-storage pile, the return travel of the conveyor may be used to transport the blocks of wood into the wood room. But where a stacker of the type shown in Fig. 17 is used, it may be necessary (especially with a stationary stacker) to install a cable conveyor, to haul the blocks from the end of the storage-pile conveyor to the wood room; this conveyor

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is similar to the piling conveyor. The blocks are propelled along the conveyor by means of attachments similar to the spurs shown in Fig. 6 or they may be of the character shown in Fig. 20. This attachment, or lug, is varied according to the shape of the conveyor bottom, etc.; but, in all cases, it is fastened to the cable by firmly bolting a suitable clamp with two or four bolts. The distance between the attachments is governed by the lengths of the blocks of wood transported.

PROTECTING WOOD FROM FIRE AND FUNGUS

47. Fire Protection in Pulpwood (According to Mr. F. J. Hoxie). Fire protection in pulpwood piles presents a problem for every mill. The construction and height of such a pile result in ideal draft conditions for any fire that is once started; and it is to be noted that streams of water played on such fire with a hose will not usually extinguish the fire until nearly all the fuel has been consumed. In the case of fire in large piles, a continuous supply of from 3000 to 5000 gallons of water per minute for a week may be required, and such a supply can be obtained only from a river or other large body of water.

First thoughts suggest the base of the pile as the place to begin fighting the fire, since the heat and smoke will make the top of the pile untenable, and water can be shot in at the base with reasonably sure aim; but this is not the case, since the wind and the air currents must be considered. The first 15 minutes is the only time that any effective fighting may be done with streams of water, when the fire is in a large pile of dry wood. Getting at the fire quickly and with sufficient water is an absolute necessity, and the best location in the early stages of the fire is unquestionably the top of the pile; here the water can be turned on in all directions, with the shortest possible range, and there will be a surer aim and less interference from wind. After the fire is well under way, the up draft caused by the heat is sufficiently strong to deflect large hose streams that are sent up from the ground; as a result, the velocity of the water will be lost, and the water will come to rest directly over the point where the up draft is greatest. The nearer to the fire the hose stream is located the greater are the possibilities of penetrating this up draft by the force of the water and thus getting at the fire. With moni-

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tor nozzles (swivel nozzles on stationary pipes) or large hose connections distributed at short intervals along the top of the pile, it will be possible to keep out of the smoke in the early stages, when the up draft is less powerful, and there is a chance of extinguishing the fire; whereas a few minutes later, the chances of success are very doubtful, no matter what is done.

48. Fire prevention by means of water spray has far greater possibilities in preventing pulpwood losses than fire extinguishing. To extinguish a fire in a large pile of dry wood, when the fire has been under way about 15 minutes, is next to impossible. Each pound of wood requires 1 gallon of water to absorb the heat generated in complete combustion. The rate of combustion varies, due to the amount of water contained in the wood and the amount of air available. In one of two fires of which there are records, the wood was unbarked, contained 50% moisture, and burned at the rate of 14,000 lb. of wood per minute. The other fire occurred in a large pile of dry, barked wood, and it burned at the rate of 26,500 lb. of wood per minute. Both fires were fought with hose streams. To fight the second fire, it would be necessary to use water at the rate of 30,000 gal. per min., and then the streams would have little effect until the wood was practically all destroyed. This demonstrates that when a large block pile has a fire well started in it, hose streams are practically uselsss; evidently, the only practical way of preventing serious fires is to keep the surfaces of the piles so wet that the piles cannot become ignited.

Spray nozzles undoubtedly possess possibilities for cheap and effective log pile protection. Results show that spray nozzles using 2 quarts of water per minute each, spaced at 25 ft. centers, and elevated 5 ft. above the surface of the pile, will give good results with a water pressure of 50 to 75 lb. per sq. in. at the top of the pile. The use of ¾-inch branch pipes, feeding 6 to 8 heads, also appears to work satisfactorily. Main feed pipes should be large enough to supply monitor nozzles; also, to keep down the velocity and prevent the carrying of sediment, which would clog the nozzles.

An approximate idea of how much water is required to maintain atmospheric saturation in any region, can be obtained from the observation of the average summer evaporation from any pond. In eastern United States and Canada, this figure is approximately 4 gallons of water per minute per acre. In

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calculating the volume of water required, the theoretical result should be multiplied by 4, a factor of safety, to make up for losses.

49. Decay of Pulpwood.—Rot in wood is caused principally by the growth of fungi. A **fungus** is a living plant that thrives at the expense of the pulp producing portions of the wood. Its growth destroys the fibrous character of cellulose and, in addition, frequently discolors the pulp made from the remaining wood. This growth does not affect the volume (cordage) of wood, but materially reduces the weight and, consequently, the yield per cord; the quality particularly is affected. The loss to the industry due to rotten wood and infected pulp (for mechanical pulp is also subject to fungus attack) has not been fully measured, but is known to be enormous.

Spraying the wood as just recommended would not increase rotting, but ought to reduce it. Wood that is *saturated* with water—its cells completely filled—will not rot. Wood below 20% of moisture is practically immune to fungus attack; and, while the exact moisture limits of wood destroying fungi are not known, the condition that promotes the most rapid fungus growth in the common pulpwoods is not far from the fiber saturation point, or from 30% to 40% moisture. If the moisture content is higher than this, destruction from fungi is decreased, practically ceasing when the wood contains about 60% moisture The most practical way to keep the surrounding air at saturation point, thus preventing the rapid destruction of log piles by fire and the slow, but surer, destruction by fungi, is to keep the pile continuously covered with a blanket of artificial fog, produced by means of the spray nozzles previously described.

Each variety of wood has its own particular fungus destroyers, and as the number of varieties of wood commercially available for pulp making are few, the fungus destroyers are correspondingly few. Knowledge of the habits of the several varieties of wood destroying fungi is not accurate enough to afford exact information as to the extent of their ravages as a function of their water requirements, but the amount of water in the wood is undoubtedly the important factor in determining the rapidity of rotting. It is probable that the function of the water in most cases is to displace the air and therefore kill fungus for lack of oxygen.

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The following fungus plants are found most plentifully on pulpwood: On spruce and other coniferous woods, **Lenzites sepiaria,** a brown plant, is the most common. This fungus can withstand moderately high temperatures and considerable dryness, and is therefore found frequently at the top of log piles.

Fomes roseus, a pink pore fungus, requires more water and a lower temperature and therefore is found lower down in the pile.

Fomes hirsutus, a white plant, with a fur like top and pores underneath, is a common destroyer of poplar.

Trametes serialis, a white pore fungus, is a common destroyer of coniferous woods.

Lentinus lepideus, a gill fungus, similar in appearance to the common mushroom, is not infrequently found on pulp wood. These two latter, together with the **Lenzites sepiaria** and **trabea,** are also common destroyers of paper mill roofs where the humidity is high.

These fungi also attack and destroy wood pulp.

Storage grounds for pulp wood should be clean and well drained. All old material should be removed before new stock is piled, so as to reduce the chance of infection. Coarse cinders make a good surface on which to pile wood.

THE WOOD ROOM

CLEANING THE WOOD

50. Operations in Wood Room.—The operations carried out in the wood room may include washing the wood that has been barked in a drum barker; cleaning up wood that has been imperfectly barked; barking the blocks on knife barkers, when an exceptionally clean pulp is desired; splitting large blocks; removing rot spots and rotten strips; reducing the blocks to chips for chemical pulp; screening, crushing, or re-chipping the chips. The use of a hot pond, in which to soak and wash the wood, aids in the barking and cleaning process.

Wood that has been peeled or barked by the dealer only needs inspection and cleaning of occasional sticks. Some mills that make sulphate (kraft) pulp do not bark the wood; this is not the best practice, however, since the bark consumes chemicals without any compensating gain in fiber.

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After the blocks are delivered to the wood room, they may or may not be cleaned before going to the chipper room (where they are cut into chips for chemical pulp) or to the grinder room (where they are ground into mechanical pulp). In general, there are four ways of handling the blocks of wood in the wood room, each of which will now be described.

51. Methods of Cleaning Wood.—(*a*) Some mills take the barked blocks direct from the storage pile and convey them to the chipper room or grinder room without further cleaning.

(*b*) Some mills take the unbarked blocks from the storage pile, convey them to the wood room, and put them through the barking drums there located; from here, the freshly barked blocks are conveyed direct to the grinder room or chipper room. When this plan is followed, the barking drums are run winter and summer. Sometimes, warm water is showered on the blocks, or they are soaked in a pond of warm water, in winter, to help remove the ice that clings to the wood; but more often, cold water is used throughout the year.

(*c*) If the blocks have been barked before being piled in the storage pile, they are sometimes run into a washing drum, where they are washed and tumbled, to remove particles of bark, dirt, or other foreign matter that may cling to the blocks. The blocks are automatically discharged from the washing drum to a conveyor, which carries them to the grinder room or chipper room. In mills producing a high grade of paper, it is sometimes the custom to trim the ends of all broomed blocks on knife barkers. Such mills also use a draw knife and a small hand-knife barker, to remove bark located in recesses and any long gum streaks that occur on the exterior; they likewise use boring machines to remove knots, and they cut out rot with an ax. As can readily be imagined, only a few mills are prepared to go to such extremes, at the present time, in the preparation of wood for the manufacture of paper.

(*d*) If the blocks have not been barked in barking drums, and it is required to remove the bark by means of knife barkers, the blocks are usually dumped by the wood-room conveyor in a steel chute, slid into a large tank of water, and taken by hand from there to the knife barkers. The blocks may also be brought to the knife barkers by conveyor.

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BARKING AND SPLITTING

52. Knife Barkers.—To remove the bark from wood blocks that are about 2 feet long, a 60-inch **knife barker,** such as is shown in Fig. 21, is used. A block of wood *W* is placed horizontally on a bracket *A*; a man holds the block against the disk *T* and rotates the block by hand or by means of one of numerous barker attachments for the purpose, one of which is shown in this illustration, attached to the barker. This is a chain *E*, driven by gear *F*, counterpoised by weight *K*, and operated by handle *H*. Securely bolted to the disk *T*, which revolves at 600 r.p.m. in a cast-iron case *M*, are fastened from 4 to 7 broad knives *N* (ac-

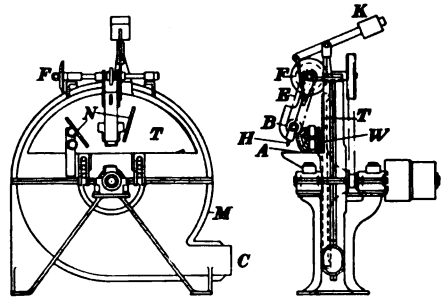

FIG. 21.

cording to the ideas of the maker), which shave off the bark as the block is revolved, either by hand or by use of the special attachment. The bark and shavings pass through the knife slots, into the opening behind the disk, and are blown, by centrifugal action, from the case through the opening *C*, into a funnel, from which they are transported on a belt conveyor to the boiler house to be burned. This size of barker requires 6 to 8 h.p. to operate it; but if direct connected to a motor, a 10-h.p. motor should be installed, to get sufficient power to overcome the starting torque. A machine of this kind has a capacity of about $\frac{3}{4}$ cord of wood per hour, the output depending on the size of the wood and the skill of the operator.

53. The barker shown in Fig. 22 differs in some details from that just described, though the principle is the same in both. The disk *D*, which is slightly convex, carries the knives *N*, which are slipped through slots (from the back) and are securely bolted.

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The blocks, which may conveniently be 4 feet long, are transferred as required from the block trough or conveyor to the rollers A, the rollers being driven by chains from the shaft T. By means of levers L_1, L_2, L_3 and clutches as at W, the proper rollers are started, and the wood is passed forward to the barking position. As the block slowly progresses past the disk, it is held close against it by roller E, which is controlled by hand wheel H. Guards F, held out by springs, keep the block from the knives, except when roller E is pushed down. Bark and

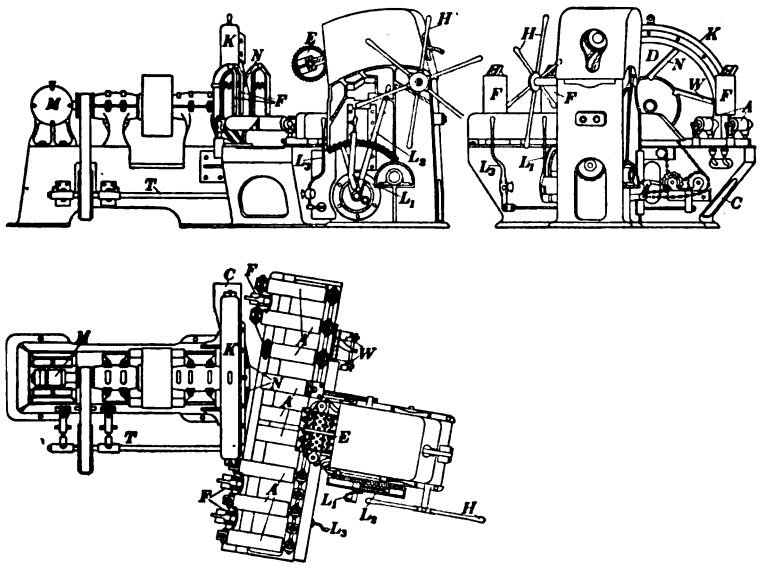

FIG. 22.

slivers pass through the disk slots, into case K, and are discharged at C. A special bearing M takes the end thrust on the disk shaft. Such a barker has a speed of 700–750 r.p.m., and it requires 8–10 h.p. to operate it.

Barkers operating on principles already explained are also used for cleaning slabs from saw mills. By using these slabs, a great waste of good fiber is prevented.

54. Knife Barkers Wasteful.—The knife barker necessarily cuts away a lot of good wood with the bark, and this is wasted, in that it cannot be used for paper making. The percentage of

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waste is greater as the diameter of the block is smaller; the loss may be enormous when the operator is careless, as from 15 to 25% of the fiber in the wood may be wasted. Operating a knife barker is very dangerous work, particularly when the block is held against the disk by hand. For the foregoing reasons, drum barkers are preferred in most mills, except for final cleaning, unless the quality of pulp demanded requires the use of the cleanest wood obtainable.

55. Splitters.—When blocks of wood that are too large to enter the grinder pocket or the chipper spout come along the conveyor, they are slid down a chute to a **splitter,** see Fig. 23, to be split into two or more pieces. After the blocks reach the splitter, they are stood, end up, on a platform *A*. The operator

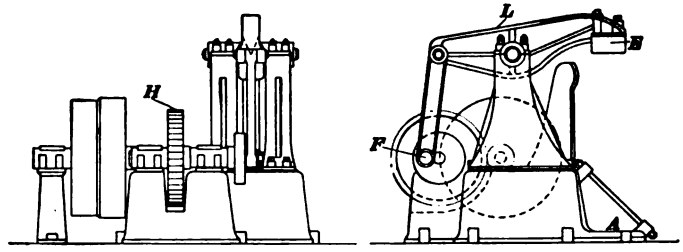

FIG. 23.

guides the upper end of the block, and when the steel splitting blade *E* reaches its maximum height, he lets the upper end of the block go forward until the block assumes a vertical position. The knife comes down on one end of the block (in the same way that an ax is brought against the end of a stick of wood) and separates (splits) the block into two pieces. The split is usually a clean break; but where a knot runs through the block, it is sometimes necessary to pull or chop the two pieces apart. After being split, the wood is placed on a truck or conveyor.

Some splitters are horizontal. Most splitters have an eccentric, as at *F*, Fig. 23, which is driven by a heavy gear *H*. In the horizontal type, a heavy connecting rod is used instead of the lever *L*. One form of horizontal splitter is operated by a steam cylinder and piston.

It is, of course, necessary that the operator look out for his fingers and feet.

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PREPARATION AND HANDLING OF CHIPS

CHIPPERS

56. Necessity of Chipping.—For the manufacture of chemical pulp, it is necessary (in order for the cooking liquor to penetrate the wood) to reduce the blocks of wood to chips that are from ½ to 1 in. long and ⅛ to $\frac{1}{16}$ in. thick. This is accomplished by machines called **chippers,** all of which are essentially alike. The blocks of wood are conveyed direct from the barkers or from the storage pile, as the case may be.

57. Description of Chipper.—A popular form of chipper that is commonly found throughout the United States and Canada is shown in Fig. 24. The wood is fed to the chipper spout *A*, end first, from the chute *E*, into which it is slid from the conveyor.

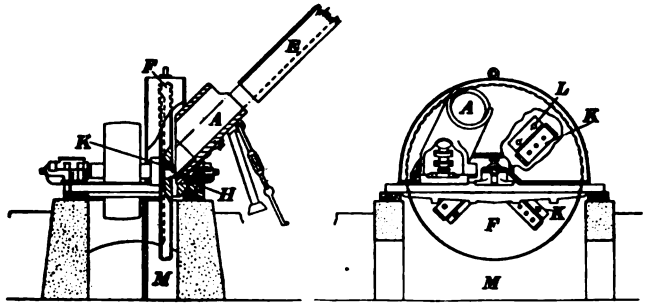

FIG. 24.

The lower end of the block comes into contact with the revolving chipper disk *F*, which, in this case, is equipped with 4 long and heavy knives *K*. The knives slice off the end of the block projecting beyond the adjustable bed knife *H*. The sliced section passes through the slot, out between the knife *K* and the check plate *L*, and thence into the pit *M*, the front of which is shown open. The knives of this machine must be changed frequently, more often in winter than in summer; when cutting spruce and balsam the knives must be replaced with a sharp set every 8 hours; on poplar, they can be used 10 hours. Sharpening is done by grinding, taking care to maintain the correct bevel.

It will be noted that the spout of this machine is inclined to the horizontal, and that it is also directed toward the rim of the disk *F*. The chute *E* is practically a continuation of the spout; it

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provides a considerable weight of wood, to exert pressure on the disk. In some mills, there is 16 feet of wood in the spout. This action increases capacity, uniformity of chips, and safety, by preventing blocks from jumping back. The angle that the chute makes with the horizontal is about 45°.

Another make of chipper works on the same principle as that just described; but, in addition to being inclined from the horizontal, the spout is inclined slightly toward the center of the disk.

A quite different type of chipper is in use in a Pacific coast mill, where the size of the timber makes it necessary to cut the logs into rough lumber. One dimension is always the same, usually 8 inches. The sticks are fed side by side over table rolls and under a heavy feed roll to the chipper. This consists of two parallel disks on the same shaft; between them are fastened the knives, which are parallel to the shaft and practically tangent to a circle that is a few inches smaller than the disks. The rapidly rotating knives slice off the chips from the face of the timbers.

58. Capacities of Chippers.—Chippers may have square or round spouts, depending upon mill requirements; they are also built in different sizes for different mills, and they may cut either round logs or slabs. The disk is usually about 88 in. in diameter. The following table gives capacities.

CAPACITY OF CHIPPERS

Diameter of disk	R.p.m. of disk	Motor h.p.	Capacity in cords per hour
88 in.	275	150	12.5
84 in.	275	100	8.25
47 in.	600	50	4.25

CHIP SCREENS

59. Rotary Type.—After being cut by the chipper, the chips contain from 1.3% to 5% of sawdust and from 1.5% to 3% of slivers. In order to separate the good chips from the sawdust and slivers, machines called **chip screens** are employed.

Figure 25 shows a chip screen of the **rotary type,** which has a length of 30 ft. and a diameter of 5 ft. The screen cylinder *A*

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is built up of circular rings E, securely bolted together, and to which the screen plates F are fastened. The rings E revolve on cast-steel rollers H, which are driven on parallel shafts K by a pair of bevel gears and pinion L. Rollers at T take care of the end thrust of the cylinder. The first (upper) 15 feet of this screen has $\frac{1}{8}''$–$\frac{1}{4}''$ holes, punched as close together as the plate will permit, to allow the sawdust to pass through them and out of the screen. The steel plate on the lower 15 feet is perforated with $2'' \times 1''$ slots, to allow the chips to pass through to the hopper N. The large chips and slivers leave the screen at the lower end,

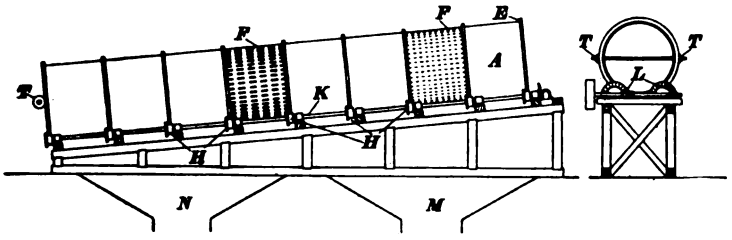

FIG. 25.

and from there are conveyed to the *chip crusher* or to the *re-chipper*. The sawdust, which falls into the hopper M, may be blown to the boiler house by means of a small blower, which is driven by a 5-h.p. motor; and the chips falling in the hopper N are conveyed direct to the chip bin in the digester house. This screen has a capacity of 18 cords per hour and revolves at 20 r.p.m.; it requires a 10- to 15-h.p. motor to operate it.

60. Shaker Type.—A flat screen of the **shaker type** is shown in Fig. 26. A reciprocating motion is given to the screen by eccentrics and rods E_1 and E_2, which are located on the driving shaft F and are connected to the tables T_1 and T_2, the latter being inclined at an angle of about 8° to the horizontal. The chips (together with the sawdust and slivers) are fed to the top of the table T_1; the chips and sawdust pass through the $2'' \times 1''$ slots in the steel plates forming the bottom of Table T_1 and land on table T_2. The bottom of table T_2 is perforated with $\frac{1}{8}$-inch holes, which allow the sawdust to drop through them to the floor or into a hopper H, from which they are blown or are conveyed to the boiler house. The slivers and chips that are too large to pass through the slots in table T_1 are conveyed to the chip crusher;

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the chips coming off the lower end of table T_2 go direct to the chip bins in the digester house.

The driving shaft of this screen runs at 175 r.p.m.; and a 10-h.p. motor is required to operate a screen large enough to screen the chips from 250 cords of wood in 24 hours. The illustration also shows chipper C, with hopper leading to bucket elevator L, which carries the chips to the screen. By so setting the eccentrics that screens shake in opposite directions, the vibration is greatly diminished.

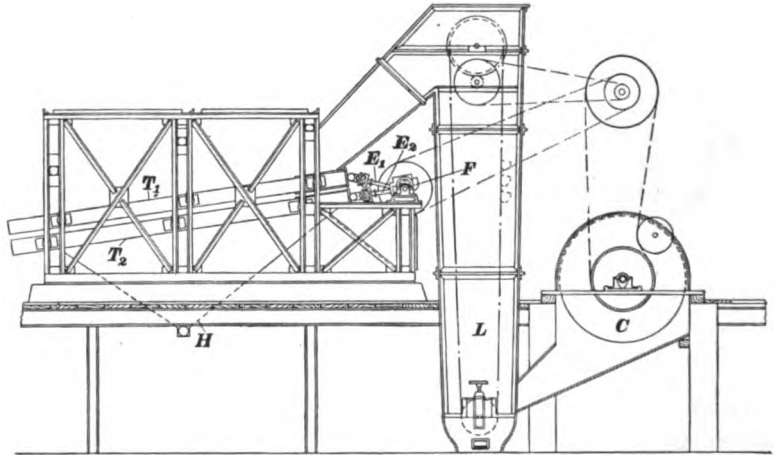

FIG. 26.

61. There are several designs of shaker screens, all operating on the same principles. The vertical supporting frames differ, and the eccentrics are sometimes placed at the center instead of at the end, as in Fig. 26. One make has a tight bottom below the plates of the lower screen, which collects the sawdust and delivers it through a spout at the lower end.

CHIP CRUSHERS AND RECHIPPERS

62. Reason for Crushing Chips.—In order to break up the chips and slivers that do not pass through the slots in the chip screens, **chip crushers** or **rechippers** are employed. Some mills place the chip crushers between the chipper and the bucket elevator and pass all the chips through the crushers; but this practice has a tendency to increase the amount of sawdust. In

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such a case, a rechipper is used on the rejections from the chip screen. In cases where the layout is similar to that shown in Fig. 26, either a chip crusher or a rechipper may be installed, to reduce the large chips and slivers to the required size. The chips from the chip crusher or rechipper are again delivered to the chip screens, to be finally accepted as chips or rejected as sawdust.

63. Types of Chip Crushers.—Figure 27 illustrates a modern chip crusher, also called a *disintegrator*, into which the chips are dumped at *A*. The chips are then forced to the center of the

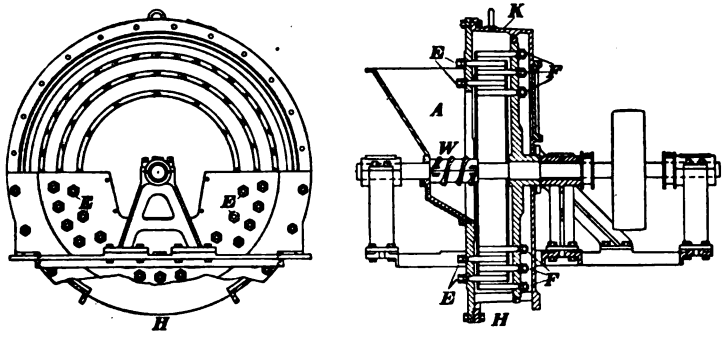

FIG. 27.

case by the worm *W*, where they are dropped between the stationary fingers *E* and the rotating fingers *F*. In this machine, the large chips and slivers are broken up, and they are then discharged at *H* to a conveyor leading to the chip screens. The disk of this machine revolves at six hundred r.p.m. in a heavy cast-iron case *K*. The machine requires from 25–30 h.p. to operate it, and it can handle the oversize chips from 250 cords per day.

64. A different type of chip crusher is illustrated in Fig. 28. The chips enter the crusher at *A*, where the arms *E*, which are hung on pivots between disks, strike the chips and crush them between the arms *E* and the adjustable knives *F*. The crushed chips are discharged at *H*. Should the arms strike a piece of metal, they will be forced back between the disks, and after passing through the knives, they will return to their original position, on account of centrifugal force. This machine is mounted on a heavy base, requires about 25 h.p. to operate it, revolves at 1200 r.p.m., and will handle oversize chips and slivers from 250 cords of wood per day.

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65. The Rechipper.—The rechipper is used by some mills instead of chip crushers, to reduce the large chips and slivers to the desired size. The chips enter the machine at *A*, Fig. 29, and drop on the rotating disk *W*, on the circumference of which are fastened several knives *K*. The chips are caught by the stationary knives *E*, cut by the rotating knives *K*, and are discharged at *H* to a conveyor that leads to the chip screens. This machine revolves at 500 r.p.m., requires 10 h.p. to operate it, and will handle the oversize chips and slivers from 100 cords of wood per day.

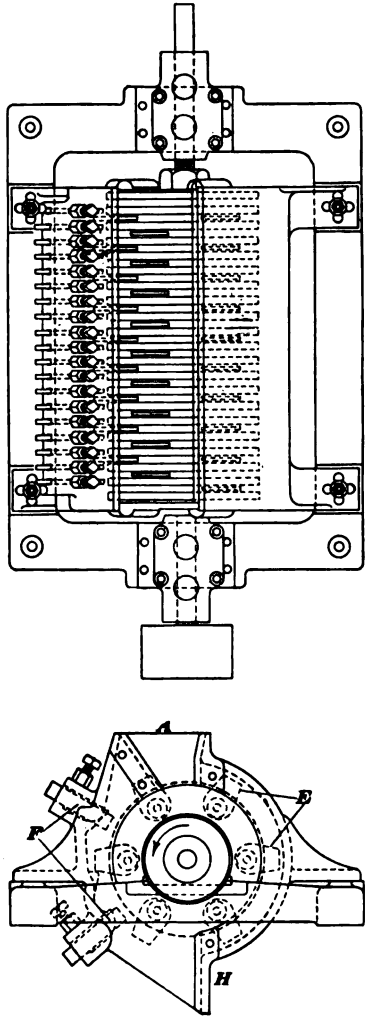

FIG. 28.

66. Chip Conveyors.—Several methods are employed for transporting the good chips from the screens to the chip bins, and most mills use some form of mechanical carrier. The bucket elevator shown at *L* in Fig. 26 is largely employed for vertical lifts. This consists of two parallel chains, which run over power-driven sprockets and smooth guides or guide rolls, and buckets are attached to the chains at close intervals. At the bottom of the elevator, the buckets are filled from a chute; they remain right side up during the upward journey, turn with the chain links over the sprocket, and empty their contents into the bin. This type is also designed to carry horizontally over the bins and empty its contents automatically where desired. Another method of elevating chips, when the lift must be vertical or nearly so, is by the use of compressed air.

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Where there is sufficient horizontal distance between the chip screens and the bins, an inclined conveyor is generally used, of which there are two common types. One type is a wide belt, which runs, on the loaded stretch, over rollers whose diameters decrease toward the center, so as to dish the belt and thus increase its chip-carrying capacity; on the return run, the rollers are cylindrical. The usual angle is about 15° to 20° with the horizontal.

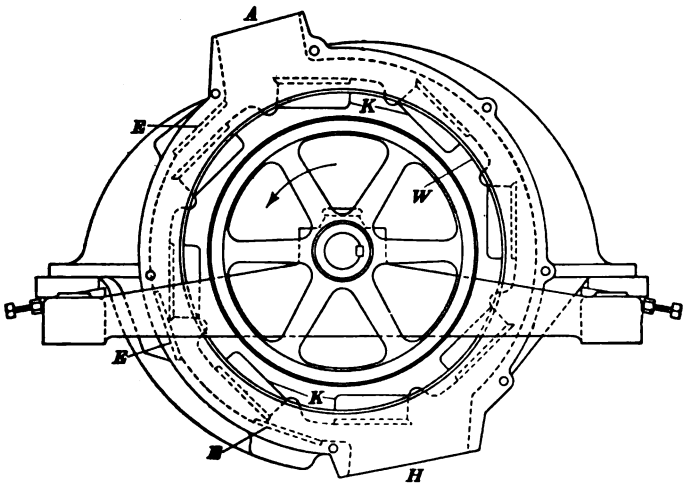

FIG. 29.

The other type is known as a **scraper conveyor;** it consists of a trough, over which slats are dragged by chains or cables. A steeper angle is possible with this form than with the belt type.

The two types are sometimes combined in a conveyor which consists of a belt with slats across it, running in a flat trough, or a belt to which the flat buckets are attached. The latter conveyor will operate on a vertical lift.

67. Weighing and Sampling.—Where a belt conveyor is used, some mills arrange to get an automatic record of the weight of the chips. Several rollers, with corresponding length of belt, form the platform of the continuous recording scale. The gross weight of the chips, as indicated by the scale, is dependent on the speed of the belt and the weight of the chips passing over it. At the same time a scraper may be adjusted to withdraw a continuous sample of chips into a suitable container. By finding the weight

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of the sample before and after complete drying, the actual net weight of the wood is found.

68. Chip Dryers.—The moisture in the chips has the effect of diluting the cooking liquor in the manufacture of chemical pulp. Since this moisture (percentage of moisture) is not constant, a variable factor is thus introduced into the cooking liquor. Some mills have tried to correct this by installing chip dryers. The principle of their operation is the same in all, the chips are caused to fall in a shower into a current of warm air. In some makes, the chips fall through a tower; in other makes, they are fed in one end of a long, slightly inclined cylinder, by which they are lifted and dropped repeatedly through a current of air that passes through the cylinder.

69. Chip Bins.—The usual practice is to store the chips in bins over the digesters, into which the chips are fed by gravity. The bins are cylindrical in shape, with cone-shaped bottoms, or they are rectangular-shaped boxes, with hopper-shaped bottoms. In either case, a removable spout is attached for filling the digesters. Each bin may serve one or more digesters; and a bin should hold enough chips to insure against a shut down of the pulp mill, in case of trouble in the wood room. Many bins are made of wood; but, because of fire hazard and short life of wooden bins, steel is now generally used for cylindrical bins and concrete is common for the rectangular type.

QUESTIONS

(1) What are the differences in kind and condition between river wood and car wood?

(2) When is the single-strand conveyor and swing saw used?

(3) What effect does water storage have on the barking operation?

(4) What important considerations govern the fire protection of pulpwood storage piles?

(5) For what is a chip crusher used? how does it work?

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PREPARATION OF PULPWOOD

EXAMINATION QUESTIONS

(1) How would you handle from log pond to block pile: (*a*) logs 6 in. to 12 in. diameter and 12 ft. long? (*b*) logs 18 in. to 30 in. diameter and 12 ft. long? (*c*) logs 24 in. to 72 in. diameter and 24 ft. long?

(2) What is the nature and purpose of a slasher?

(3) Why is it advisable to remove the bark from pulpwood? Mention the methods of doing this.

(4) Describe one type of barking drum.

(5) Describe one type of knife barker.

(6) Compare the advantages and disadvantages of the barking drum and the knife barker.

(7) If wood be driven in streams having falls and rapids, what effect is produced on the wood?

(8) Explain the principle of the bark press and state why it is used.

(9) Describe briefly two types of apparatus for storing pulpwood.

(10) How can the danger from falling blocks be avoided when taking blocks from the storage pile?

(11) What operations are carried on in the wood room?

(12) Explain the construction and operation of a pulpwood chipper.

(13) Describe the operation of screening chips.

(14) (*a*) How is pulpwood measured? (*b*) What factors affect the relation between the volume of wood and the weight of available fiber?

(15) (*a*) What is the effect of fungus growth on pulpwood? (*b*) What conditions favor the growth of fungi?

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SECTION 3

MANUFACTURE OF MECHANICAL PULP

By H. J. BUNCKE, C. E.

INTRODUCTION

DESCRIPTION AND HISTORY OF PROCESS

Note.—This Section is based on a thesis submitted by the author to the University of Maine, in partial fulfillment of the requirements for the degree of master of science. The author wishes to record here his appreciation of assistance and valuable suggestions received from the Roberts Burr Co., from the International Pulpstone Co., and from the members of the operatting and technical staffs of the Abitibi Power and Paper Co., and of the Laurentide Company.

1. Scope.—In this Section, the manufacturing process for the making of **mechanical, or groundwood, pulp** will be described, from the time the pulpwood reaches the grinder room until it is ground and ready for screening. From that point, the processes of treating the pulp apply to all kinds of pulp, and are therefore described in Section 7, on *Treatment of Pulp*. In the discussion of the quality of mechanical pulp, it has been necessary to consider also some of the features that lie outside the mechanical-pulp mill.

2. History of Process.—The manufacture of mechanical pulp, on a commercial scale, was first carried on in central Europe during the middle of the nineteenth century. On this continent, the first pulp mill was located at Curtisville, Massachusetts, and started operation in 1876. At that time, mechanical pulp was used as a filler, and, being cheaper, it rapidly replaced the more expensive chemical pulps, both wood and rags. Very little attention was paid to the quality of the fibers, so long as the cost of the more expensive materials formerly required was reduced.

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Poplar wood was the chief raw material in the beginning. As the process developed, however, and new woods were used, the superior quality of pulp made from spruce and balsam wood,

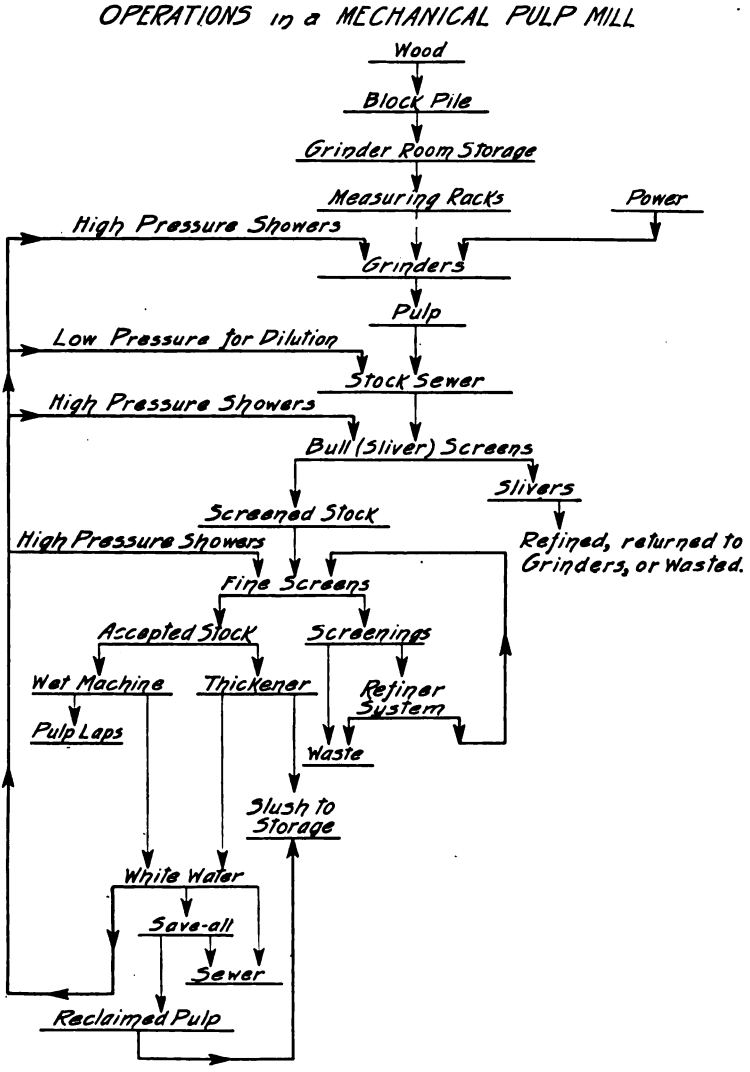

FIG. 1.

and the ease with which these logs could be floated to the mill, in contrast to poplar, which will float only a short time, caused the mills to adopt it for their use.

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3. General Description of Process.—The manufacturing process for mechanical pulp causes a separation, by mechanical abrasion, of the small wood fibers that go to make up the pulpwood structure. This must be done in a machine that will operate continuously and at a minimum cost of production. It is desired to make the maximum amount of pulp from each cord of wood ground, and the mixture of fibers after screening must be suitable for commercial use. The accompanying diagram Fig. 1, shows the operations carried on in the groundwood pulp mill and their relation to one another. Screening and subsequent operations are discussed in the Section on *Treatment of Pulp*.

Although the principles on which the process is based are simple, there is a wide variation in the details of their application, according to the policy of individual mill managements as to the quality and quantity desired and the degree of control of conditions obtainable. In a large majority of cases, accurate data, concerning the grinding conditions and quality of wood used are not taken; consequently, much of the work is carried out by rule of thumb, on a qualitative basis.

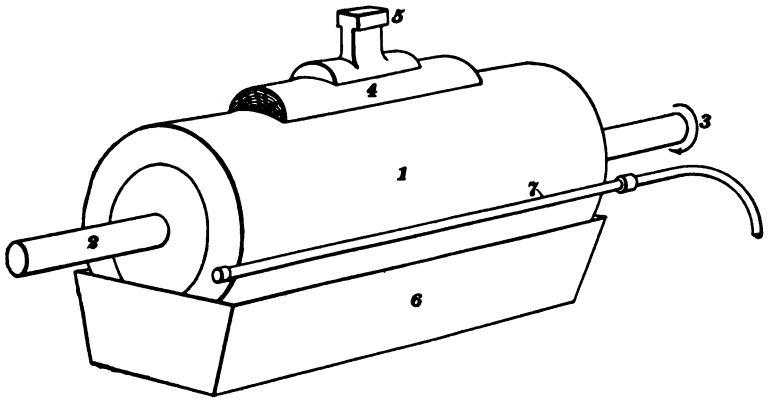

FIG. 2.

4. Fig. 2 shows in a simple way the principles involved in the grinding process. Here 1 represents a gritty sandstone, mounted on a heavy steel shaft 2 and revolved by a source of power at 3. The wood 4 to be pulped is placed on the surface of the stone, with its length parallel to the width of the stone, and pressed upon the surface of the grindstone by a suitable source of pressure 5. In this way, the power supplied at 3 is absorbed in mechanical fric-

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tion between the surface of the revolving stone and the surface of the stationary sticks of pulpwood, from which the fibers are being separated. Water is added to the pulp in the pit 6 beneath the grindstone, by means of shower pipe 7, which sprays upon the face of the grindstone. The heat generated in friction is absorbed by this water, which also washes the fibers from the surface of the stone.

5. The early types of pulpwood grinders were poor in design and construction, required high maintenance costs, and were low in production.

One of the early types of pulpwood grinders had a vertical shaft, and was driven by a water wheel set in a pit beneath it. Eight (8) pockets were placed around the periphery of the stone, and the wood was pressed against the revolving grindstone by means of a gear-driven mechanism.

The first grinders mounted on a horizontal shaft had from three to five small pockets, mechanical feed of wood against the grindstone, and a complicated governor arrangement, to maintain a uniform speed, with a variable power consumption. This grinder was, however, the machine from which our present grinders were developed.

MILLS AND RAW MATERIAL USED

6. Distribution of Mills.—The location of the supply of pulpwood and cheap power have been the controlling factors in the distribution of the present mechanical-pulp mills. This is due principally to the large quantities of wood used by the process and to the low prices received for the pulp. Mechanical-pulp mills, therefore, have been confined to the districts in which these requirements are met.

The New England States, Northern New York, Michigan, Wisconsin, and Minnesota contain the largest number of mechanical-pulp mills in the United States, because of their natural supply of wood and power and adequate facilities for transportation to points of consumption. In Canada, the Provinces of Quebec, Ontario, and British Columbia are large producers of mechanical pulp.

7. Wood Used.—The soft, or coniferous, woods, are those most used in the manufacture of mechanical pulp, and spruce

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furnishes by far, the largest proportion of the raw material. In 1920, about 846,000 tons of mechanical pulp were made in Canada, and about 1,571,000 tons in the United States during the same period; over 80% of the wood used was spruce.

Balsam fir, hemlock, and jackpine are the other soft woods consumed. White birch and poplar, or aspen, are the hard woods most used for the manufacture of mechanical pulp; they are, in the majority of cases, ground and mixed with pulp from spruce wood. The limiting factor in the amounts of these hardwoods which are used with spruce pulp, is the required physical quality of the final pulp mixture. The bulk of mechanical pulp is used in the manufacture of newsprint paper at high machine speeds.

8. An extensive study of the quality of mechanical pulp made from different kinds of wood was made by the Forest Service of the United States in 1916.[1] The pulps were manufactured into paper and printed on standard presses, with very encouraging results. However, if some of these woods are to be substituted for spruce, the grinding conditions will have to be adjusted to suit the wood ground, and the rate of production will, in some cases, be reduced. Table I gives the yield in number of pounds of mechanical-pulp fiber on the bone-dry[2] basis per 100 cu. ft. of solid, barked wood. The table was compiled from information given in Bulletin 343, to which reference has just been made.

9. Uses of Mechanical Pulp.—Mechanical pulp is used in the cheaper grades of paper and board, which are required for only a short time and then destroyed. Deterioration takes place in these papers, accompanied by loss of strength, color, and finish of the sheet on exposure to light and air, due to chemical changes in the non-cellulose constituents of the wood. It is usually mixed with small amounts of chemical pulps, to make what is known as news, wall, cheap book, cheap manila, cheap tissues, rotogravure, wrapping, bag, and building papers. Boxboard, container board, and wall board contain very large amounts of mechanical pulp. It is also used to absorb explosives in the manufacture of dynamite.

[1] United States Department of Agriculture Bulletin No. 343, Groundwood Pulp. Part 1. The Grinding of Cooked and Uncooked Spruce. Part 2. Substitutes for Spruce in the Manufacture of Groundwood Pulp. By J. H. Thickens and G. D. McNaughton. (Published in 1916 in Pulp and Paper Magazine, in Paper, and in other journals.)

[2] Bone-dry fiber means moisture-free fiber.

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TABLE I

Species	Yield
Balsam fir	1910
Red fir	1915
White fir	2000
Alpine fir	2060
Amabilis fir	1870
Lowland fir	1950
Noble fir	1920
Eastern hemlock	2030
Western hemlock	2160
Tamarack	2620
Western larch	2100
Lodgepole pine, Montana & California	2140
Western yellow pine	2060
Jack pine	2150
Lodgepole pine:	
Fall cut	2500
Spring cut	2400
White pine	1885
Englemann spruce:	
Montana	2250
Colorado	2000
Sitka spruce	2100
White spruce	2400
White birch	2950
Aspen	2200
Black gum	2600

PHYSICAL PROPERTIES OF MECHANICAL PULP

10. Physical Properties Affected by Grinding Process.—In the production of mechanical pulp the following properties are of importance: Freeness, uniformity, strength, color, finish of sheet (when made into paper) cleanliness, and resin content. A control of these quantitatively is the ideal to be arrived at in the manufacture of this class of pulp.

In the following discussion of the properties of mechanical pulp, it is assumed that its properties are not changed by treatment in the beater or jordan before being made into paper.

The variables encountered in the grinding of wood materially affect the physical properties of the pulp produced and its operating characteristics on the machines in the manufacture of paper. The pulp which is used is a mixture of: (1) some of the wood fiber

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in the natural form; (2) bundles of fibers; (3) fibers that have been re-ground, in some cases, to a fine wood flour. An idea of how much the wood fibers are ground up may be had by comparing photomicrographs of mechanical pulp fibers in the Section on *Refining and Testing of Pulp*, Part 2, with photomicrographs of chemical pulp fibers made from the same wood, which appear in the Section on *Properties of Pulpwood*.

The mixture of wood fibers is suspended in water and, after being passed through screens, for the purpose of removing the very coarse materials or slivers, goes to the paper machines. On the machines, the part which forms the sheet of paper is either a long, endless, fine-wire sieve, approximately 60 mesh, or a large cylinder having for its surface a wire similar to the endless one referred to. The action on these wires is one of draining; the water passing through the wire leaves the strained-out fibers on the wire surface in the form of an interwoven mat.

11. Freeness.—If there is very much coarse fiber and insufficient filler (fine, fluffy fiber) in the stock,[1] the fiber mat will not pack well; it will be of open texture, the water will pass through quickly, and the stock will be called **free stock.** On the other hand, if there is a large amount of fiber that is short, mixed with fiber with frayed out ends, a more dense mat of fiber will be made. The water will then pass through the fiber mat more slowly, and the mixture will be known as **slow stock.**

The *rate* of this drainage action, or the relative **freeness** of the stock, while not a physical property of an individual fiber, is a valuable indication of the quality of a pulp mixture. It is closely related to uniformity, strength, and the finish of the mechanical-pulp paper.

The *freeness tester* and the *sedimentation tester* are the two pieces of apparatus used for laboratory and mill tests of freeness. These are described and illustrated, and the procedure for making tests is explained, in the Section on *Refining and Testing of Pulp.*

12. Fig. 3 shows **freeness tester.**[2] It is made up of two main parts—a container and a funnel. The container *A* which holds the stock while drainage takes place through the fiber mat, has a wire bottom *B* on which the mat forms. The water strained through the fiber mat passes into the funnel *C*, which has two outlets. The one at the bottom *D* is $\frac{1}{8}''$ in diameter, and the

[1] Stock—name given to mixture of fiber and water.
[2] Paper. Vol. XIX. No. 5.

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other E, on the side of the cylinder, is $\frac{1}{2}''$ in diameter. The hole at the bottom is not large enough to pass a large volume of water under a low head; consequently, there is an overflow from the side hole E. A deflector keeps the water from running directly into the overflow. A graduated cylinder F is used to catch this overflow. The volume of water, usually measured in cubic centimeters, passing through this overflow is a measure of the relative freeness of the stock, a free stock causing a large overflow, and a slow stock, a smaller overflow.

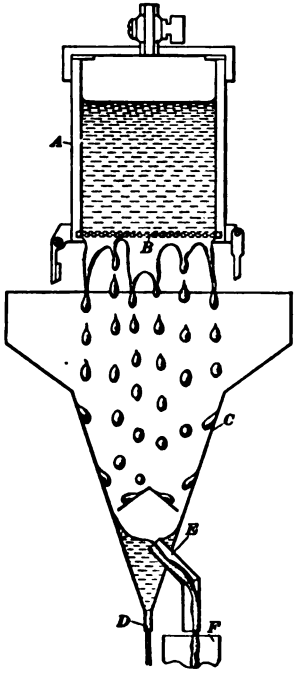

FIG. 3.

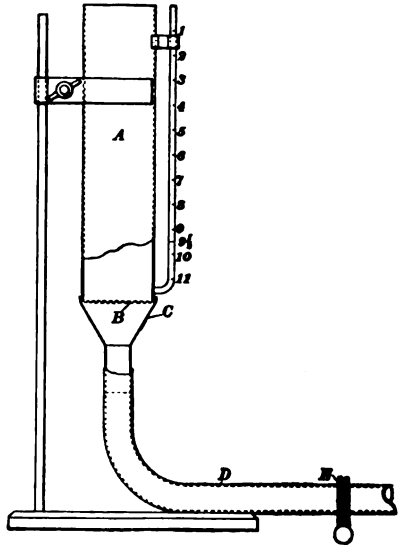

FIG. 4.

13. Fig. 4 shows a successful sedimentation tester.[1] It is made up of a graduated glass cylinder A, for holding the stock to be tested, having a conical metal bottom C. A wire screen, similar to the one used for a paper machine, covers the bottom of the cylinder at the joint B between the cylinder and the cone. Attached to the bottom of the cone is an outlet hose D, with a clamp E for stopping the flow of water during the time the apparatus is being prepared for the test. To determine the drainage

[1] Pulp and Paper Magazine. Vol. XV, page 217.

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action of stock, the clamp *E* is closed, and the apparatus is filled with clean water to the level of the bottom of the wire. The stock to be tested is then poured into the graduated cylinder, and the level in the cylinder is noted. The clamp *E* is then released, and the time taken for the level of the stock in the cylinder to fall a standard amount, under standard conditions, is noted. The practice of the originator of the apparatus is to fill the tube to the zero (0) mark and determine, by a stop watch, the time it takes the surface to reach the 9½ mark. As the stock level falls, a fiber mat is formed on the surface of the wire, and it offers a resistance to flow, in proportion to the freeness of the stock.

14. Importance of Standard Conditions.—In order that the character of the pulp indicated by these pieces of apparatus may be representative of the fibers alone, it is necessary to correct all observations to: (1) a standard consistency of stock; (2) a standard temperature of the fiber suspension. A standard consistency is necessary because the rate of fiber deposition, and, consequently the thickness of the fiber mat and resistance to drainage action, varies directly with the percentage of fiber per unit volume of the suspension. The viscosity of water decreases as the temperature increases, and it is very evident that the less viscous a fluid is the more easily it will pass through a filtering medium. Hence the necessity for a standard temperature.

In the use of these pieces of apparatus for control work, considerable skill is required, in order that the results may be reliable. Experience has also shown that the results that they give are comparable only when they are obtained by the same apparatus, under like conditions. This means that comparisons made among different mills are not directly comparable.

15. Uniformity.—From a consideration of the factors involved in the drainage of water from a mass of fibers of variable length, supported on a wire sieve, it is apparent that different combinations of fiber lengths and structures may result in the same rate of drainage action, or freeness, when supported on the same wire sieve. Under certain conditions, therefore, two stocks of the same freeness may be made up of fibers of entirely different characteristics. This indicates that more detailed analysis is necessary concerning the variation in size of the individual fibers that go to make up the stock of the freeness desired. The first question to be decided is whether the fibers are wanted as near

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one size as possible, or whether what is wanted is a certain gradation in size of the fibers to give the desired freeness. As a result of trial, a fiber mixture of a certain size variation may give the best results in paper-machine operation; some means is necessary for determining, and an expression is desirable for indicating, this particular size variation, for comparison with stocks made in the future.

16. At the present time, three methods are available for gaining this information: (1) the blue glass; (2) the microscope; (3) lantern slides.

These three pieces of equipment give valuable information as to the quality of mechanical pulp, but do not give conveniently the details on a quantitative basis.

The manufacturing process for mechanical pulp is such that it is difficult to make a definite fiber size graduation on a particular grindstone or group of grindstones; but if the graduation most suitable be known, the desired result could be made up by a mixture of stocks, the characteristics of which were known.

17. In the blue glass method, the fibers are diluted to a consistency of .05% to .1%. The suspension is placed in a frame about 12 inches square, with 1½ inch sides, having a bottom made up of a piece of blue-colored glass. Only a small amount of the suspension is placed in the frame, so that the individual fibers may be plainly seen against the blue background. From an examination of the contents of the frame, the relative proportions of the different sized fibers are then estimated. The amount of information that this method gives depends to a large extent on the experience of the operator; but, in any case, the results obtained are qualitative only and are subject to personal variations. This method, however, is in very general use in pulp mills today. A modified apparatus is explained and illustrated in the Section on *Refining and Testing of Pulp*.

18. With the microscope, it is possible to get more specific information as to the size variation by actual count of fibers, and by estimation of their sizes and forms. This method, while useful, is seldom used for quality tests on a routine basis. It has also been found that the grading of mechanical pulp by microscopic analysis does not always agree with strength tests on sample sheets. Some typical photomicrographs are shown in the Section on *Refining and Testing of Pulp*.

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The lantern is in much more general use for examination of fibers on a routine basis. A thin suspension of the fibers to be tested is placed on a lantern slide, and is then projected upon a screen, where an estimate is made of the size variation of fibers. In some cases, the fibers are compared with a slide that is considered to show a standard of fiber variation, and an estimate is made of how the sample compares with the standard in fiber length, ground-up wood fibers, and slivers.

19. Strength.—The strength of mechanical pulp depends on: (1) the method of grinder operation; (2) the character of the wood used; and (3) the felting qualities that the pulp has in the formation of a sheet. When a sheet of mechanical-pulp paper breaks, the break is due, to a large extent, to the pulling apart of the interwoven fibers rather than to an actual breaking of the individual fibers. The longer, thinner, and more flexible that the fiber can be made, therefore, the less the amount of more expensive chemical pulps needed to be mixed with mechanical pulp, to give it the strength that is required of the paper into which it is made. There are some papers, however, in which groundwood is used merely as a filler, and under these conditions of use, a long flexible fiber is not so necessary.

For routine strength-testing of mechanical pulp, the pulp is usually screened and made into test sheets. These may be tested as explained in the Section on *Paper Testing*.

20. Color.—The color of the pulp resembles very closely that of the wood from which it is made. For some grades of paper, such as news and book, a pulp of a white color is desirable; while for others, the color is sacrificed to get an increase in strength. Steaming the pulpwood before grinding gives a stronger pulp, but the fiber is darker in color than that made from unsteamed wood. For special uses, mechanical pulp at the present time is being bleached on a commercial scale. (See Section on *Bleaching of Pulp*.)

21. Finish.—The ability of mechanical pulp to take a finish on the surface of the sheet is another of its properties. After being formed into a sheet on the wire of a paper machine, it is dried on hollow rolls filled with steam, and is then passed between the heavy steel rolls of a calender. The latter operation has an ironing-out effect, which gives the sheet a smooth surface, on which printing ink takes well. Here, again, the quality of

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the wood used and grinding methods are important. A free stock will not take a good finish, because the large sized fibers and open texture of the sheet are noticeable after the finishing treatment. A slow stock takes a finish easily. This is because the fibers are not so large, and the spaces between them are well filled with the small fluffy and broken fibers. Broken fibers, *i.e.*, weak and stubby stock, will not give a good surface or finish. In some papers in which mechanical pulp is used, such as heavy wrapping paper and container board, the finish is not of importance.

22. Cleanliness.—The cleanliness of the pulp depends upon the care with which the pulpwood has been barked and the pulp screened, the cleanliness of the water used for suspending the stock, and the general care that is taken to keep foreign material from accumulating in, or getting into, the system through which the stock is passed. A frequent cause of dirty pulp is incomplete washing of the tanks on clean-up days, when accumulation of sand (from sharpening grindstones) and slime may be stirred up and mixed with the pulp, when the mill is again started in operation.

23. Resins.—In some cases, the resinous materials contained in the pulpwood cause the pulp made from it to be unsuitable for use on high-speed machines. These resins accumulate on different parts of the paper machine, which causes breaks of the sheet by filling up the meshes of the wires and felts and by sticking to the rolls. The effects of these materials are usually greater during summer conditions of operation, when the grinding temperatures are high and wood is being taken directly from the river to the grinders. Trouble from resin is also more noticeable when using freshly cut wood.

These qualities of the finished pulp should be kept in mind as the processes of manufacture are studied. A definite object is thus set up, which is to be attained only by constant care and attention.

QUESTIONS

1. Why are soft woods preferred to the hard woods for mechanical-pulp manufacture?
2. About how much bone-dry pulp can be obtained from woods commonly used?
3. In what products is mechanical pulp used as a raw material?
4. Name five physical properties of mechanical pulp.

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5. What is meant by "freeness"? how is it tested?
6. What causes (*a*) a free stock, (*b*) a slow stock?
7. On what does the strength of mechanical pulp depend?

GRINDERS AND GRINDING

HAND-FED GRINDERS

24. General Description.—The most familiar pulpwood grinder is of the three-pocket type, which grinds wood twenty-four inches long. These grinders produce from 5 to 7 tons of air-dry pulp[1] per day; they use from 300 to 500 horsepower to the grinder; and are usually driven by hydraulic turbines at a speed varying from 200 to 260 r.p.m.

Some grinder installations, of three-pocket type, may grind wood 32 inches long, and a few mills have hand-fed grinders that use sticks 48 inches long; but this makes the manual labor very exhausting. For applying pressure to the wood in the 48-inch grinder size, there may be two hydraulic cylinders on each pocket. Four-pocket grinders are also in use. They are generally operated so that there are three pockets grinding all the time; the fourth pocket is filled with wood, and is put into operation when one of the other three pockets is thrown off for charging with wood.

25. Fig. 5 shows a **three-pocket pulpwood grinder.** The grindstone 1 is mounted on a steel shaft 2 by clamping between a pair of heavy steel flanges 3. Power is applied to the shaft 2, which rotates the stone; the shaft is supported by a pair of water-cooled bearings 4, mounted on the pair of base plates 5. The covering over the stone is made up of two side plates 6, connected by means of cross braces 7, known as *bridge trees.* To complete the covering over the stone, the pockets 8 are placed in the space between adjacent bridge trees and side plates, and are supported above the stone by means of the heavy steel bolts 9, which are attached to the bridge trees. Mounted upon each pocket is a hydraulic cylinder 10, containing a piston similar to that in a steam engine. The reversing valve 11 controls the

[1] Dry pulp fibers absorb moisture when exposed to the air. The amount absorbed varies with the humidity of the air. **Air-dry pulp,** commercially, is 90% bone-dry fiber and 10% water.

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flow of water, under pressure, in and out of each end of this cylinder. When water is admitted on the top of the piston, the piston advances toward the stone, and piston rod 12 transmits the water pressure by means of the **pressure foot** 13, which acts upon the sticks of prepared wood placed in the pockets. When the wood is ground, the reversing valve is operated, and the pressure foot 13 is raised, to allow a new charge of wood to be put into the pockets. The stone is cooled and cleaned by means of the white water,[1] which flows through shower pipe 14 upon the back

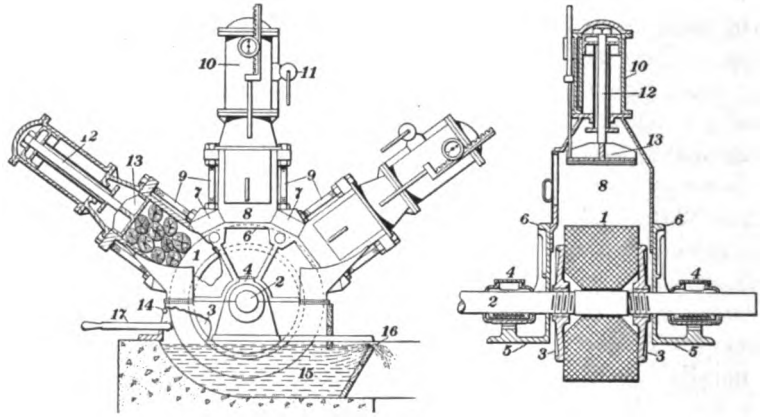

FIG. 5.

of the stone. The mixture of pulp and water collects in the pit 15 beneath the stone and falls over the dam 16 of the pit, into the stock sewers (channels or pipes) beneath the grinders. When the stone becomes dull, it is sharpened with a burr, passed over its surface by means of a lathe or trueing device 17, which is mounted on the back of the casing.

GRINDSTONES

26. Origin.—Natural sandstones having special physical properties are in universal use for the manufacture of mechanical pulp. They are quarried for commercial use in the Newcastle

[1] **White water** is water returned to the grinder room from other parts of the mill, after most of the fibers are strained out of it. The name comes from its color, which is due to particles of fiber, resins, and oils that it contains. The solids are from 0.05 % to 0.12% by weight.

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District in England, in Virginia and Ohio, in the United States, and in the province of New Brunswick, in Canada.

27. Qualities of Grindstones.—The two qualities of a grindstone which most strongly influence its production of pulp are: (1) the so-called **grit,** consisting largely of small quartz grains of varying size; (2) the **matrix** or **binder,** usually of a softer material which cements the grains together. Too little or too soft a binding material gives what is known as a **soft** stone, from which the quartz particles crumble away easily. On the other hand, an excess of binding material or excessive tenacity of the matrix results in what is known as a **hard** stone which is difficult to sharpen and the grinding surface of which tends to glaze. In order to withstand the complex stresses of service, the material of the pulp-stone must possess considerable mechanical strength, a quality which is improved by seasoning.

28. Grit.—The grit of the stone separates the fiber from the pulpwood stick; consequently, the size and shape of these particles affect the production of the largest amount of good fiber, with the smallest waste in coarse and very fine materials. The process of removing the wood fibers must be one of tearing and rubbing. If the particles in the stone have sharp angular corners, the wood fibers will be cut and ground into short fiber bundles; there will be coarse material, which will make the stock free on the paper machines. On the other hand, if the grit particles are round, they will slide over the wood fiber, require frequent sharpening, and produce a pulp of irregular quality. The most satisfactory grit, therefore, is sub-angular in form, *i.e.*, the corners on the particles rounded off. In general, a stone of fine grit produces a fine-fibered pulp, and a coarse grit produces a coarse and shivy pulp.

Fig. 6 is a photomicrograph showing a medium-grit sandstone; Fig. 7 shows a coarse-grit stone. The relative size of grains and of matrix are readily compared.

29. An analysis of the size of the particles that make up the sandstone may be used for comparing the size variation of the grit. To make the analysis, the grit particles are carefully separated from the binder in an earthenware mortar, and are then screened through sieves of varying number of meshes to the inch. The Canadian Department of Mines Bulletin No. 19 gives the following analysis of stones that have been in successful use:

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FIG. 6.

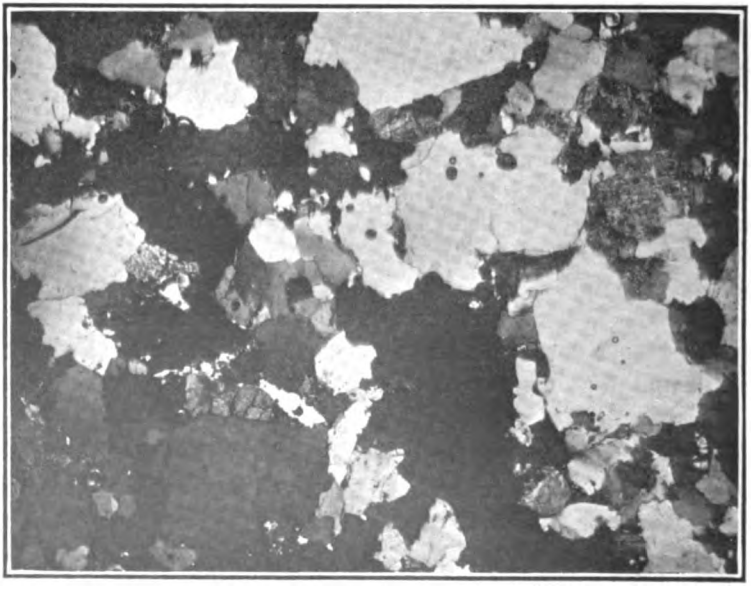

FIG. 7.

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All pass through 20-mesh sieve	English Pulpstone	American Pulpstone, Ohio	American Pulpstone, Virginia
Retained on	Per cent	Per cent	Per cent
28-mesh sieve.....	9.55	3.65	2.86
35-mesh sieve.....	14.83	14.56	9.04
48-mesh sieve.....	27.20	40.85	43.15
65-mesh sieve.....	16.27	12.14	18.55
100-mesh sieve.....	17.55	9.25	10.01
150-mesh sieve.....	5.90	5.25	4.24
200-mesh sieve.....	2.02	2.58	1.85
Through 200-mesh sieve .	6.50	11.37	10.07
	99.82	99.65	99.77
Loss.....	0.18	0.35	0.23
	100.00	100.00	100.00

The material passing through the 100-mesh sieve is practically all the soft matrix or binding material. It is evident, therefore, that the percentage by weight of this material varies from 14.60% to 19.55%.

In submitting these figures, it is not to be inferred that they are the limits within which all good pulpstones would be included. They are given simply as examples of stones which have given satisfactory commercial service for pulp for newsprint paper.

It may be said that the larger the amount of coarse grains in the stone the higher the rate or production; but, at the same time, the fiber mixture is proportionally increased in coarseness.

30. Binder.—As the name implies, this material partially fills in the voids between the quartz particles and holds them together. Binders may be argilaceous, siliceous, ferruginous or calcareous; they are usually mixtures.[1] The ideal binding material would be one that would wear away just enough faster than the quartz particles to keep the grit exposed the right amount at all times. Under these conditions, dressing the surface of the grindstones by means of a steel burr would not have to be done so frequently.

[1] For description of these materials, the reader is referred to standard works on Geology.

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31. Mechanical Strength.—After fulfilling all the requisites for the production of pulp, grindstones must be able to withstand the severe stresses that they undergo in service. These are complicated, and they result from the following causes:

(*a*) The pressure due to clamping in place between the flanges, which is increased by the power transmitted through the shaft and absorbed at the surface of the stone.

(*b*) The centrifugal force due to rotation, tending to burst the stone.

(*c*) The pressure on the surface of the stone by the wood being ground.

(*d*) Local overheating, or sudden cooling at the surface, causing the stone to scale.

(*e*) Tangential shearing stress, due to the retarding effect of the pressure of the wood against the rotation of the stone.

There are no data available to show what the combined stresses amount to, but practice has set up certain operating rules, which are given in other parts of this Section.

32. Seasoning.—Sandstone occurs in nature in laminated planes, situated at varying depths below the surface of the earth. When removed from the quarry beds, the stones are soft and contain certain amounts of moisture, commonly called *quarry sap*. This liquid usually runs out of the stones in a week, but the stones will still be soft when this has stopped. By continued exposure to air, the stone will slowly harden or season, a process somewhat like the setting of concrete. This should be allowed to take place in a covered room, which protects the stones from the sun, rain, and extreme temperature variations. The stones should also be supported above the floor, on narrow wooden strips, during the seasoning period. This is to allow the air to circulate around the stone and prevent uneven seasoning.

To allow thorough seasoning, pulpstones should not be put into service until about a year after their removal from the quarry; but authorities differ as to the length of time that is required. When a partly seasoned stone is put into use, it will probably operate satisfactorily until the outside seasoned shell is worn through, after which the softer material may scale, and pieces of it may break off.

33. Artificial Grindstones.—Artificial grindstones have been made and tried out under commercial conditions of operation;

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but as yet, they have not been generally satisfactory. In artificial grindstones made up of re-inforced concrete, cracks occurred, due probably to the different expansion coefficients of concrete and steel. Grindstones made of iron, with their faces roughened, were also tried out and found to be unsatisfactory. When the surface was first dressed, the pulpwood was sawed into fragments, and when the rough edges wore off, the rate of production was practically nothing. European pulp manufacturers claim to have made recently a satisfactory artificial grindstone. In this country pulp manufacturers are still experimenting with artificial stones in the hope that a satisfactory stone will be developed, in view of its importance to the industry.

34. Sizes of Stones.—The most common size of hand-fed grindstone is one cut to a diameter of 54 inches and having a 27-inch face for grinding 24-inch wood. Through the center of the stone, a rough circular hole is cut from face to face, and through this, the shaft of the grindstone passes. The hole must be large enough to allow clearance of 2 inches around the shaft for centering up the stone. Both ends of the smaller stone are ground flat and parallel. It is against these end surfaces that the steel flanges press, in holding the stone in position on the steel shaft.

The grindstones used for grinding 24-inch, 32-inch, and 48-inch wood are usually made 54 inches in diameter. The faces on the respective sizes are usually 27, 36, and 54 inches.

35. Life of Grindstone.—The life of a sound stone varies from six to eighteen months, depending on the hardness of the stone, the frequency of sharpening, and the method of operation. As a stone wears down, a higher speed of rotation is required to maintain the same peripheral speed of the stone. Usually a 54-inch stone is worn down to 40 inches in diameter.

OTHER DETAILS OF HAND-FED GRINDERS

36. Shaft and Flanges.—Grinder shafts are usually of forged steel, and from 6 to 9 inches in diameter, depending upon the total power transmitted. In the cross-section shown in Fig. 8, the steel couplings 1 and 2 are used for connecting with water-wheel shafts or for connecting grinders together. The shaft is threaded at 3 and 4, the thread at one end being right-hand, and

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other end, left-hand. Split, brass, taper bushings 5 and 6 are threaded upon the shaft and on inside of steel flanges 7 and 8. The grindstone is held in place on the shaft by tightening up the flanges, which clamp the stone solidly to shaft. When installing grindstones, great care must be taken to make certain that the direction of rotation is such that the threads will be tightened, and not unscrewed, when the grindstone is in rotation in the grinder.

The slight taper from a to b, and from a' to b', may be used on flanges, so that they will grip at the outer edge first and thus

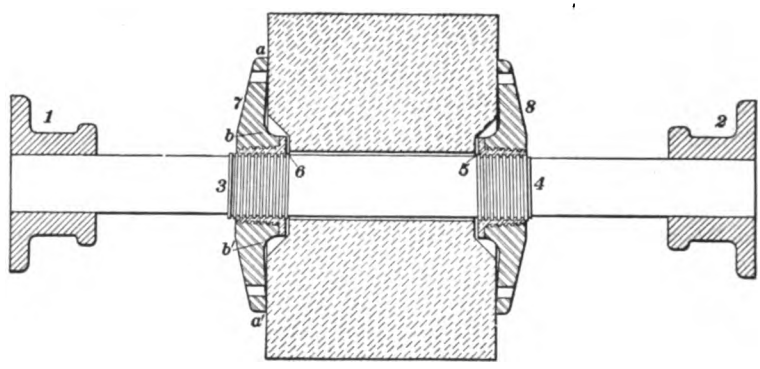

FIG. 8.

insure a firm grip on the stone's face. There is on large stones, and might, with advantage, be on small stones also, a spherical or conical enlargement, which conforms to the concave inside face of the flange. This helps to overcome bursting strains; and it also tends to hold the stone parts together, when serious breakage occurs. The tapered thread connection between flange 7 and bushing 6 and between flange 8 and bushing 5, assists in clamping the split brass bushing tightly to the flange. The additional length of the threads at 3 and 4 allows the grindstone to be set up on the shaft at a small distance either side of center, which is sometimes required when placing stones inside different casings.

37. There are other methods of fastening the stones to the shafts, which will not be discussed in detail here. The object of all such connections is to hold the stone tight on the shaft, and to provide a means for taking a worn-out stone off a shaft when the threaded connections are pulled up so tight that they are difficult to unscrew. Under these conditions, the stone is cut off the

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shaft by means of rock drills; and with the strain taken off the threads, the flanges may be unscrewed more easily. Since, in some cases, the strain on the flanges is sufficient to damage the threads, bronze bushings are useful. The threads on a bushing may be stripped, while those on the shaft and flange, being of steel, are saved.

38. Bearings and Foundations.—The two adjustable bearings for supporting each grindstone are placed outside of the founda-

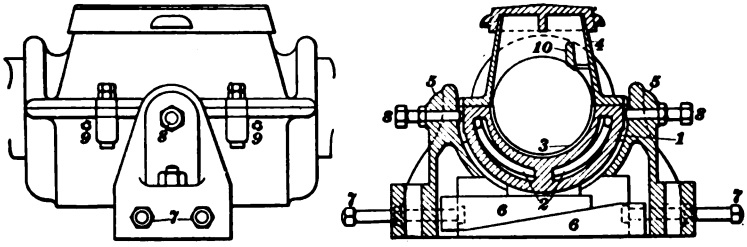

FIG. 9.

tion casing. Fig. 9 shows a cross section of a typical bearing of this type. It consists of a bottom section of bearing 1 containing a water jacket 2, through which water is circulated to carry off the heat generated in the bearing. At 3, the bearing metal, in which the shaft rotates, is shown. On top of the bearing is a

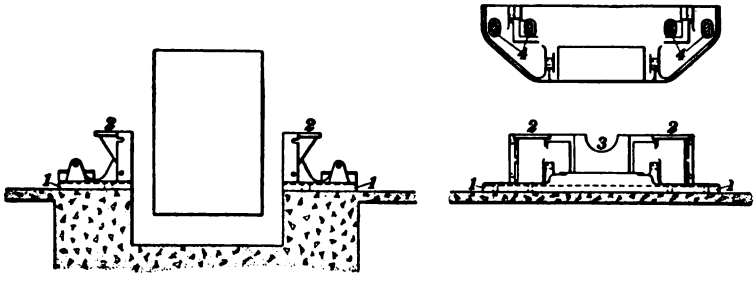

FIG. 10.

bearing cap 4, with removable cover, which contains a lubricating oil box 10 and supply wicks. The bearing may be moved in both horizontal and vertical directions inside the saddle casting 5. The vertical motion is obtained by means of wedges 6, which are moved by adjusting bolts 7. The horizontal motion of bearings is accomplished by means of the adjusting bolts 8. Pipe

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connections 9 to the side of the bearings are for a supply and discharge of cooling water.

The bearings are anchored to foundation plates shown in Fig. 10. These are made of a heavy cast-iron base 1. The vertical sides 2 form part of the bottom enclosure for the stone. The shaft passes through hole 3 in the vertical sides, and must be packed, to prevent leakage of pulp through the casing. During the operation of the grinder, the uplift caused by the pressing of the hydraulic cylinders against the wood blocks is transmitted through these plates to the foundation bolts, which pass through holes 4.

39. Side Casings and Bridge Trees.—The side casings 1 and 2, Fig. 11, form a continuation of the enclosure of the stone. They

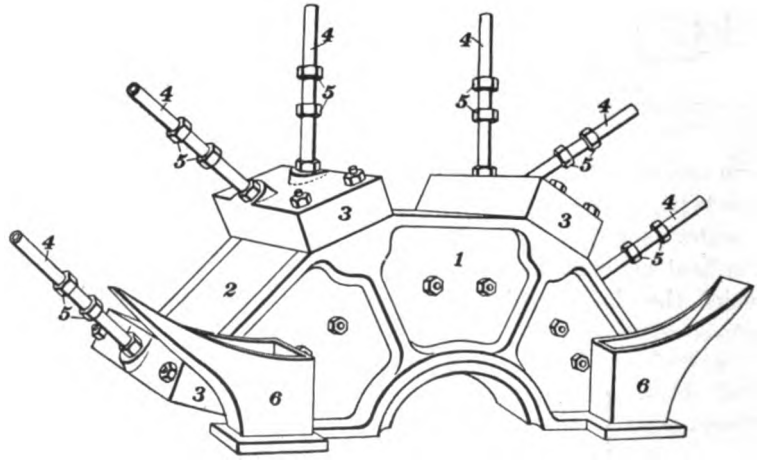

FIG. 11.

are joined by means of heavy, cast-iron, reinforced connections 3, usually called **bridge trees.** While also forming a section of the covering over the grindstones, the bridge trees support the grinder pockets at their proper distance above the face of the stone. The large bolts 4 with jam nuts 5 pass through holes in the lugs on the sides of pockets, and are used for varying the height of pockets above the stone's face, as it is gradually worn down. The nuts must be frequently adjusted; for, if the space below the bottom of the pocket and the face of the stone exceeds about ¼ inch, slabs of partially ground wood pass out of the pockets, with the rotation of the stone. These slivers may accumulate in the grindstone pit

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and cause overheating of the stone; but if this does not occur, the slabs are rejected from the coarse-screening process, and are collected by some mills for re-grinding. Attached to the front side casing are two save-alls 6,6. When the doors on the front of the two side pockets are opened for re-charging, any pulp that flows out of the pockets passes into the pit beneath the stone through these save-alls.

40. Grinder Pockets.—Fig. 12 shows the details of a typical grinder pocket. These pockets are made of cast-iron, and they furnish the support for the grinder cylinders. Projecting into the pocket, there is a steel piston rod 1, carrying a cast-iron pressure foot 2. The pressure foot has an area equivalent to that of the pocket, with the exception of the small clearance required for travel up and down in the pocket, as the wood is ground. Attached to the pressure foot is a small rod 3, which projects out through the top of the pocket and is used as an indicator, to show the rate at which the wood is being ground in the pocket. In some cases, an indicating dial, with rack and pinion gearing to magnify the rate of advance of the pressure foot, is attached to this indicator rod.

Teeth in the side of the pocket are shown at 4. These teeth are set to just clear the stone's surface. The pulp ground from sticks of wood in the pockets passes through these teeth, and around the front and back ends of the pocket at 5 and 6, into the pit beneath the stone. Usually teeth are only used on the side of one pocket—the pocket on the side toward which the top of the grindstone is traveling. The sides of the other two pockets are solid, and, in some cases, doctors or scrapers are attached to the bottom of these pockets; by scraping on the stone's surface, the pulp fibers are pushed to both ends of the pocket, and are thus prevented from being reground by passing under one of the succeeding pockets. In some types of grinders, where the pockets as a whole are not moved up and down to accommodate wear of stone, there are movable steel plates, with teeth on the bottom, which keep the slabs of wood from passing out of the pocket unground. These plates are bolted to the sides of the pocket, and they perform the same function as the adjustable pockets. A disadvantage of this latter type of equipment is the longer stroke required by the hydraulic cylinder piston when the stones are worn to a small diameter. It will be noted that in Fig. 12, there are two sets of lugs 7 shown on the side of pocket in place

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of one set, as indicated on the general assembly drawing of the three-pocket grinder, Fig. 5. These are for the adjusting bolts.

The stops shown at 10 keep the blocks of wood from being pushed in too far. Slots in the sides of the pocket, at 11, serve as guides for a sheet-iron door, which protects the workman by keeping blocks and hot pulp from popping out. This pocket has for its support, four side bolts instead of two, because it is for a grinder for wood 32 inches long. The front and back flanges on

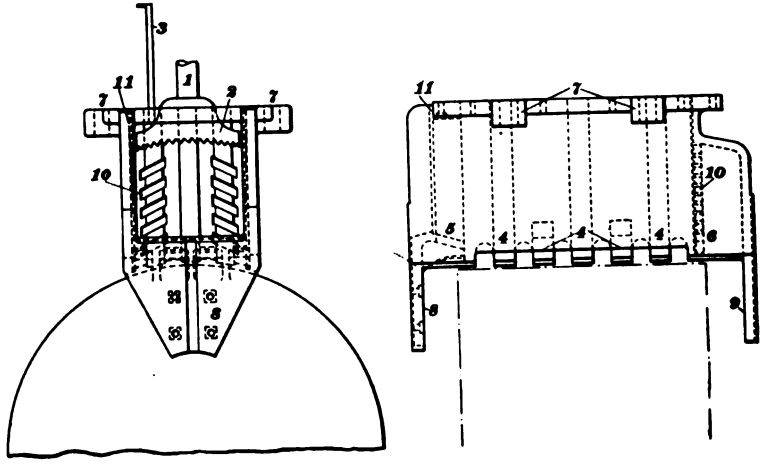

FIG. 12.

the pocket at 8 and 9 are bolted to the front and back side casing by means of bolts that project through casings, which have slotted holes for the bolts to facilitate the adjustment of the pockets.

41. The limit to size of wood that can be ground in pockets is governed by the dimensions of the rectangular opening at the front end and the length included between back 6 of pocket and the flange 5 at front of pocket. In comparing grinding conditions in the manufacture of mechanical pulp, the pressure per square inch of pocket area is calculated from the hydraulic cylinder dimensions. The total pressure on the piston in pounds, divided by cross-sectional area of the pocket, in square inches, gives the intensity of pressure per square inch of pocket area. This is not; however, the actual pressure per square inch of wood on stone, since the area of wood in contact varies, as the wood grinds down with the changing diameter of the blocks fed in.

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42. Hydraulic Cylinders.—Fig. 13 shows a cross section of a hydraulic cylinder with attached pressure foot. It is made up of a cast-iron cylinder 1, lined with a thin, seamless, cylindrical brass tube 2, which makes a very smooth surface for the piston to slide on. High-pressure water is supplied to reversing valve 3, through connection 4; this water is then passed through the port 5 to the top of the piston 6. At the same time, the water in the cylinder below piston 6 is allowed to pass out of cylinder, by means of port 7, to valve 3, and out of the valve through outlet 8. As the piston is forced down, the water pressure is transmitted through piston rod 9 to pressure foot 10, and so to blocks of wood placed in pockets. To prevent leakage of water from the high-pressure to the low-pressure side of the piston, packing, shown at 11, is placed in between the sections of the piston. To prevent leakage out of the cylinder, packing glands are used on the piston rod and tail guide rods, as shown at 12 and 13, respectively. Some grinders are made without tail rods.

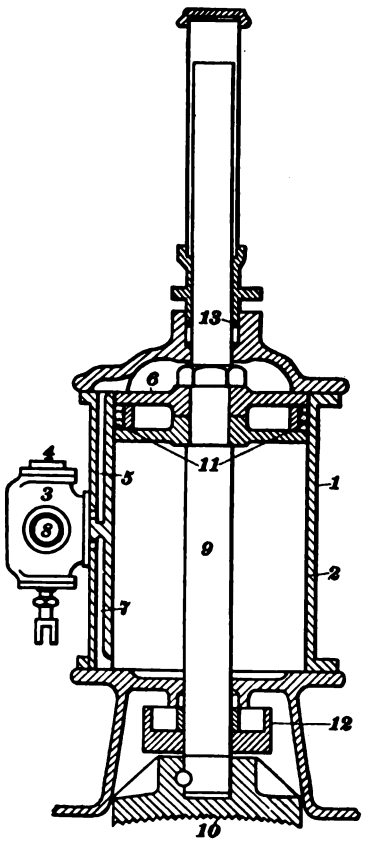

FIG. 13.

The amount of pressure that is delivered to the pressure foot is directly proportional to the intensity of the water pressure admitted to the cylinder. For hydraulic cylinders of different diameters, if the water is under the same pressure per square inch, the total pressure on the wood is proportional to the square of the cylinder diameters.

43. Reversing Valves.—Fig. 14 illustrates a cross section of the reversing valve shown at 3, Fig. 13. This is known as a balanced piston type of valve, because its construction is such that the pressures on top and bottom of valve are always balanced; hence,

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the friction required to be overcome in operating the valve is very small. The valve is made up of a cast-iron body 1, which is bolted to the side of the hydraulic cylinder on face 2. The ports 3 and 4 connect up with ports 5 and 7, Fig. 13. The inside of the valve is made up of a seamless, brass, cylindrical tube, extending from 5 to 6. High-pressure water may be admitted from inlet 7 into this tube at 5, and in end 6, by passing through port 8. The brass tube is perforated around the surface with holes at 9, 10, 11. The perforations at 9 connect with the top of the hydraulic cylinder through port 3, and perforations at 11 are connected with the bottom of the cylinder through port 4. The perforations at 10 connect, by means of circular port 12, with the outlet of the reversing valve, shown as a dotted line at 13, on the back of the valve. On the inside of the brass perforated tube, a spool-shaped valve piston 16 is shown, with leather packing cups at heads of the valve at 17 and 18; these cups form a water-tight joint between the moving valve piston and the brass tube. The motion of the valve piston is controlled by means of valve rod 19.

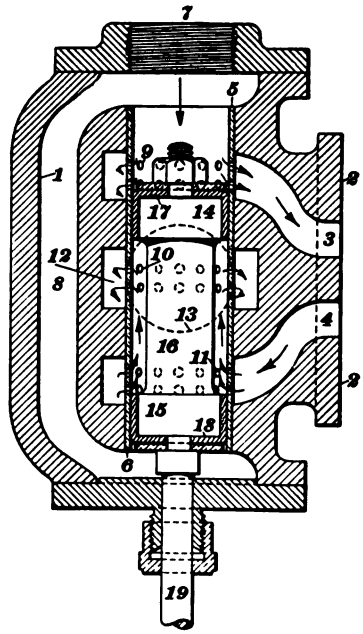

FIG. 14.

In Fig. 14, the valve piston is so set that high-pressure water is passing through holes 9, and into the top of the hydraulic cylinder, through port 3. At the same time, the valve position is such that the water contained in cylinder below piston is passing through port 4, through holes 11, along between valve spindle 16 and the inside of the circular brass tube, out through holes 10 into outlet ports 12, and then to valve outlet 13. When the wood is completely ground in the pocket, the valve rod 19 is pushed up by a lever, so that valve end 15 is above port 4. This allows high-pressure water to pass into the cylinder at 4, causing the piston to rise in the hydraulic cylinder. Water is discharged from top of the hydraulic cylinder at 3 and out of valve at 13, as before.

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The total area of each of the sets of holes 9, 10, and 11 has an important effect on the rate of movement of the hydraulic piston, on the back pressure caused by the discharging water, and on the rate of water consumption. A study of the example in Art. **48** will enable the reader to interpret these factors.

44. Sharpening Devices.—There are several different types of devices made for sharpening and trueing-up the surface of grindstones. They may be divided, according to the construction of the sharpening device, into three groups: the hand-operated stick; the mechanical-feed lathe; and the hydraulic-feed lathe.

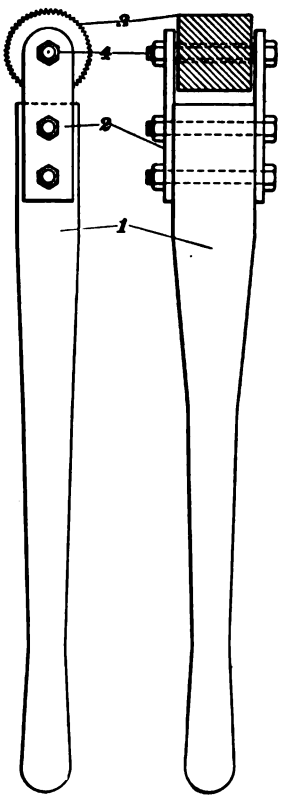

FIG. 15.

The **hand-operated stick** is made of an iron or wooden handle 1, Fig. 15, with iron straps 2 bolted upon the sides. The burr 3 revolves on a shaft 4, the axis of which coincides with the axis of the burr. With this sharpening device, the amount of treatment and rate of treatment depend upon how hard the operator presses the burr against the stone and upon how fast he moves it across the stone's face.

45. A type of **mechanical-feed grindstone dresser** is shown in Fig. 16. It consists essentially of two cast-iron side plates 1, connected by means of brass surfaced ways 2. Mounted upon these ways is a movable carriage 3. The carriage 3 contains a bronze nut 4, which is threaded to the cross-feed screw 5. By turning the handle 6 in one direction, the carriage will travel across the face of the stone. Reversing the rotation of handle 6, brings carriage back to starting point. For pressing the burr against the surface of the stone, a screw feed, similar to the carriage feed, is used. The burr is first mounted in a burr holder 7, and is fastened to the burr carriage by tightening bolts 8. By turning handle 9, the burr carriage may be moved so that the burr presses

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against the stone. The degree of sharpening is governed by the pressure at which the burr is forced against the stone, as the handle 6 is turned to feed the burr across the stone's face.

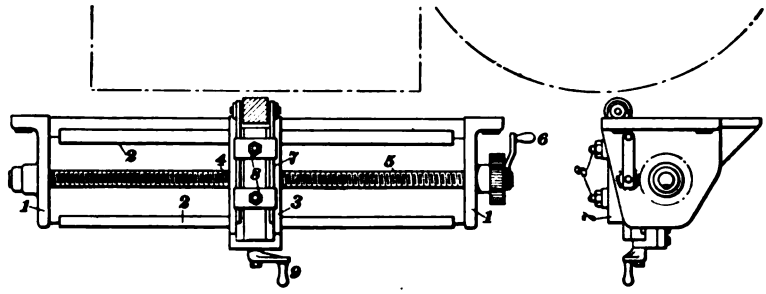

FIG. 16.

46. One of the types of **hydraulic-feed grindstone dresser** in commercial use is illustrated in Fig. 17. It differs from the one just described, in that both the cross-feed carriage and the burr carriage are operated by high-pressure water.

The hydraulic dresser shown in Fig. 17 consists of a set of end supports 1 and 2, carrying the base of the lathe in curved saddle tops, which allow the lathe to be so rotated that the burr may be applied to stone at any desired angle. The upper surface 3 of

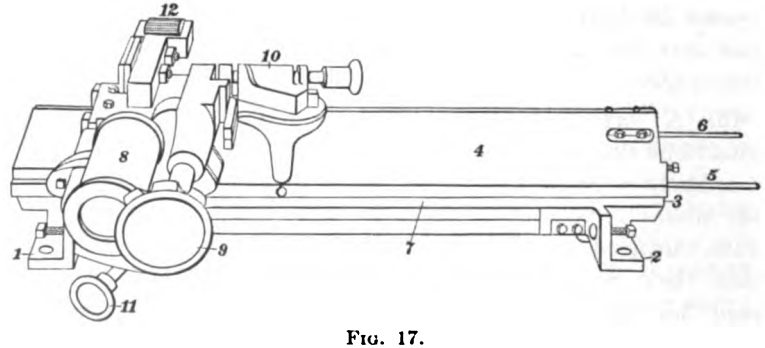

FIG. 17.

the base makes up the sliding ways, over which cross-feed carriage 4 is moved by means of a hydraulic cylinder and piston, similar in principle to that used on grinders, located below the carriage cover 4. When the carriage moves for operating the burr, it slides along way 7. Water under high pressure is supplied to the cylinder by means of hose connections to carriage for

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both inlet and outlet water at 5 and 6. The burr-feed motor is shown mounted on top of the cross-feed carriage.

This dresser is made of four essential parts: the feed motor or hydraulic cylinder 8, which forces burr against stone; the hand wheel 9, for controlling depth to which the burr is allowed to cut into the stone; the automatic return mechanism 10, controlling the return of the carriage to starting point and the withdrawal of the burr from contact with the stone; and the valve 11, for starting and stopping the hydraulic lathe in operation. The burr, in another type of holder, is shown at 12.

47. Grindstone Pit.—Fig. 18 represents a cross section of a grindstone pit. It consists of a curved bottom 1, the outlet of

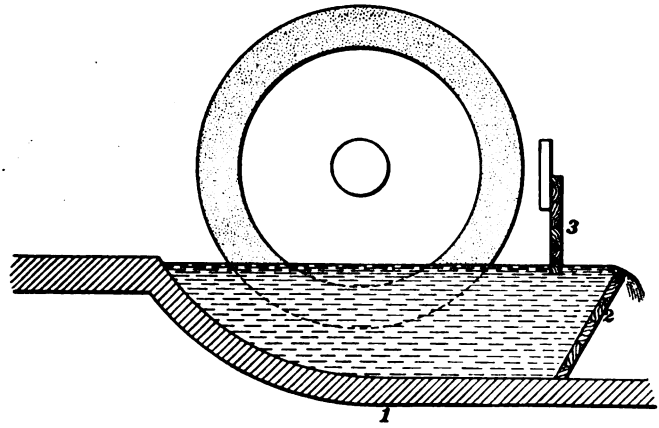

FIG. 18.

which is made up of a series of adjustable dam-boards 2. The wood fibers, mixed with water, fill the grinder pit to a level that is governed by the height of the dam-boards 2, and then fall over the dam into the stock sewer or channel, which is located below the grinder pits. This level also governs the depth of immersion of the grindstone in the pulp. There is also an adjustable apron-board 3, attached to the front of the grinder, which may be raised or lowered, in accordance with the height of the dam-boards 2. The apron boards are set with their level below the top of the dam-boards 2, thus making a seal and keeping the rotation of the stone from throwing pulp out into the grinder room. The object of immersing the grindstone in the stock is to aid in cleaning the surface of the stone, to equalize the temperature of stone, to

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prevent loss of fibers (due to low consistency), during filling of pockets, and to keep stock from being thrown out of pockets.

The width of the dam-boards 2 is the same as the distance between the side casings, and the usual clearance between stone and bottom of pit is 6 to 8 inches. The distance between apron 3 and the dam-boards 2 varies from 6 to 15 inches. There is much variation in the arrangement of the grindstone pits, caused principally by the different ideas of the various pulp makers. The stone rotates left-handed, or counterclockwise.

48. Piping.—Fig. 19 shows the general arrangement of the piping on a hand-fed grinder. *A* is the high-pressure water main,

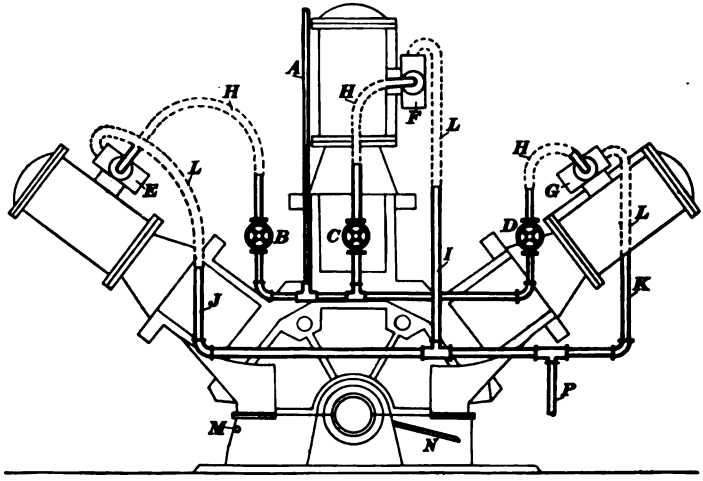

FIG. 19.

with regulating valves *B*, *C*, and *D* supplying pressure water to the reversing valves on each cylinder at *E*, *F*, and *G*. Since the type of grinder shown is of the movable-pocket type, it will be noticed that there is a section of high-pressure, rubber hose *H* attached to the reversing valve, to allow pocket adjustments to be made. The connections *J*, *I*, *K* from the reversing valves, are for carrying away the water relieved from the cylinders, and for discharging it at *P* into the stock sewer. These also have a rubber-hose section *L*, as in the case of pressure water.

An example will serve as the best means of calculating the amount of high-pressure water that will be required. The case of a three-pocket grinder, using wood 32 inches long, with a

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pressure of 65 lbs. per sq. in., in a 16-inch diameter, 20-inch stroke, cylinder will be used.

Volume of water used for one cylinder full..... 2.33 cu. ft.
Time for piston to rise from bottom of cylinder to top..... 11.6 sec.
Rate of advance of piston..... 1.724 in. per sec.
Volume of water required by this cylinder when rising..... 0.200 cu. ft. per sec.
Rate of advance on other two cylinders while grinding wood..... 0.9 in. per min. = .015 in. per sec.
Volume of water taken by other two cylinders = $\frac{2.33}{20} \times .015 \times 2 =$ 0.0035 cu. ft. per sec.
Total volume of high-pressure water required, adding 10% for loss in leakage = $(0.2 + 0.0035) \times 1.10 =$ 0.22385 cu. ft. per sec.

To handle this volume, a 2½-inch diameter feed pipe to each grinder was used, branched off into 2-inch feed pipes to each of the individual pockets.

From the above example, it is apparent that the rate of water consumption while the pressure is actually on the wood is small compared with the consumption while raising the pressure foot to receive a new charge. With the piping arrangement as indicated, therefore, the size of feed pipe is determined by the rate of water consumption during pocket filling, and this, in turn, is dependent on the number and size of holes in the reversing valve on the hydraulic cylinder and on the back pressure against which the relieved water discharges. An increase in the number or size of the holes in the reversing valve would reduce the time interval, shown as 11.6 sec. above, and would increase the velocity in pipes at the same time.

At *M*, Fig. 19, is shown the shower-water pipe on the back of the stone, for clearing it of fiber. A brass or iron pipe is used, perforated with holes varying from $\frac{3}{32}$ inch to $\frac{1}{4}$ inch in diameter, placed at from $\frac{1}{4}$ inch to $\frac{3}{4}$ inch centers, depending upon whether fresh water or white water is used. During operation, the amount of water used is varied by adjustment of valve on shower water inlet.

Holes smaller than $\frac{3}{16}$ inch in diameter are not entirely satisfactory when white water is used on the shower pipes, because they continually plug up with fibers and require frequent cleaning.

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49. Pulp mill operators have different ideas as to arrangement and details of shower pipes, but the essential features involved may be given here. Enough water must be supplied to thin the fibers ground from the pulp-wood stick to a consistency of 3½% to 6%, when carrying on the hot-grinding process. This requires from 3 to 6 gallons of water per minute per ton of pulp made on the grindstone per 24 hours. This water must be so distributed over the face of the stone that it may be uniformly cooled, and that the fibers may be washed out of the grooves in the stone's surface. Therefore, to get the best cleaning, the holes should be as small as can be satisfactorily used with the shower water. The volume of water used is fixed within the limits as mentioned above; consequently, the best cleaning will result by using a larger number of small holes and a pressure of from 15 to 30 lb. per sq. in. on the shower pipe.

Connection for fresh water to water jackets on bearings is shown at *N*, Fig. 19. The outlet is on the side opposite the inlet to bearing. This is usually water at a pressure of from 10 to 15 lb. per sq. in. The volume of water depends upon the heat to be absorbed. An average figure for cooling water would be from 5 to 10 gallons per minute per bearing. It would no doubt be possible to design satisfactory bearings without the water-cooling feature. The conditions under which they would have to operate however, are seldom met with in mill practice. It is difficult to keep bearings clean, properly lubricated, and in perfect alinement; hence, the heat generated because of poor conditions must be absorbed by the cooling water.

QUESTIONS

1. Make a sketch of a three-pocket grinder and indicate the principal parts.
2. (*a*) What is white water? (*b*) why is it so called?
3. Describe the structure of a pulpstone.
4. Mention some of the stresses to which pulpstones are subjected.
5. (*a*) Why is it necessary to season a pulp grindstone? (*b*) how long does it take?
6. Why is a bronze bushing used between the threads on the grinder shaft and those on the flanges?
7. Why is it better to have grinder pockets adjustable than to simply move the fingers that retain the slivers?

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8. If a grinder cylinder is fed with water at 60 lb. per sq. in. and the piston is 14 inch in diameter, what is the total pressure on the wood? Ans. 9236.3 lb.

9. Using your answer to the preceding question, if a stick of wood 10 in. in diameter and 32 in. long is ground half through, what is the pressure per sq. in. of wood in contact with the stone? Ans. 28.86 lb. per sq. in.

MAGAZINE GRINDERS

PURPOSE AND DESCRIPTION

50. Purpose of Magazine Grinder.—The **magazine grinder** has been developed to decrease the cast of grinding: (1) by means of units having greater capacity and requiring less attendance; (2) by getting an increase in production per foot of face of stone by improvements in design.

Magazine grinders on this continent grind wood 48 inches long, and make from 16 to 25 tons of air-dry pulp in twenty-four hours. They have about 25% more grinding area, *i.e.*, of wood, exposed to the surface of the stone per foot width of grinding surface, and they use a stone with an initial diameter about 10% larger than the average three-pocket hand-fed grinder, *i.e.*, about 60 inches to 62 inches in diameter as compared with 54 inches; the output per inch of stone width is approximately 50% greater than in the three-pocket type. Magazine grinders are also practically all driven by constant-speed motors, on which a constant predetermined load is maintained. This allows a greater average peripheral speed than is used on most hand-fed grinders, and reduces the power losses due to speed variation. These factors are the principal causes of the greater production of the magazine grinder per foot of width of grinder surface.

For hand-fed grinder operation, it takes from 250 to 300 man-hours in attendance per 100 tons of air-dry pulp made per twenty-four hours, while for the same production on a magazine grinder installation, only from 110 to 130 man-hours are required. The saving in operation costs are, therefore, very much in favor of the magazine grinders.

Magazine grinders are usually connected in pairs and are driven by synchronous motors of from 2400 to 2800 h.p. capacity, operated at from 215 to 240 r.p.m.

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The other special features of the magazine grinder will be found in the detailed description which follows.

51. Description of Grinder.—Fig. 20 shows a longitudinal section of the most common automatic magazine grinder. The grindstone *A* is mounted on a heavy horizontal shaft *B*, and is clamped in place by means of conical steel flanges *C*, which fit corresponding conical projections on the sides of the grindstone. The covering over the stone is made up of side frames or casings on each side, (not shown in figure), horizontal pressure feet *D* on the ends, tall, vertical, wood magazines *E* on the top, and heavy adjustable plates *F* on the bottom, which are advanced as the stone wears down. Cylinders *G* are operated by hydraulic pressure, as is the case with the hand-fed grinders. Piston *H* in the cylinder on the left is shown moved to the extreme left of its stroke, and the wood in the magazine *E* has descended into the space left empty by the withdrawal of the piston and pressure foot *D*. The piston *H* in the cylinder on the right has advanced, so that the charge of wood is almost all ground. The lug *I* on the pressure foot *D* is just pressing against the valve trip-rod lever *J*. This operates a mechanism that moves valves *G*, Fig. 23, so that the piston is moved to the right, thus opening the pocket and allowing wood to fall into it by gravity. Water is sprayed on stone surface, through shower pipes *L*. The stone is shown partly submerged in a mixture of fiber and water, the amount of submergence being controlled by means of overflow dam *M*. The stone dressing or trueing device, operated by hydraulic cylinder, is shown at *N*.

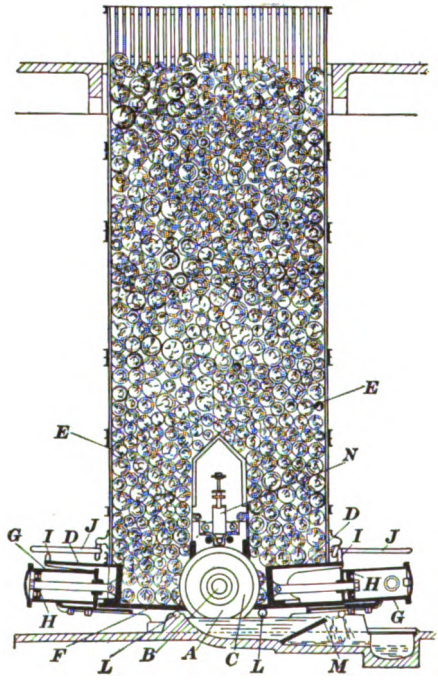

FIG. 20.

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DETAILS OF MAGAZINE GRINDER

52. Operation.—The operation of this grinder is almost entirely automatic. Wood is charged into the top of magazine *E*, Fig. 20, and is placed with its axis parallel to that of the stone. As the wood is ground in each pocket, mechanical and electrical equipments control the sequence in which pocket filling may occur, and also maintain a uniform load on the prime mover. The wood sometimes binds in the pockets or arches over the pockets; it is therefore necessary to have a man to attend to each three or four grinders, to adjust difficulties of this kind.

53. Fig. 21 shows the Canadian development of the magazine grinder. In this design, the magazine is made in two separate compartments hinged to the supporting floor beam. This form

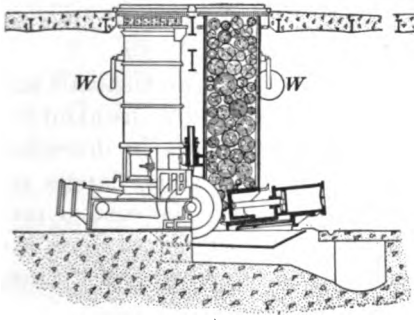

FIG. 21.

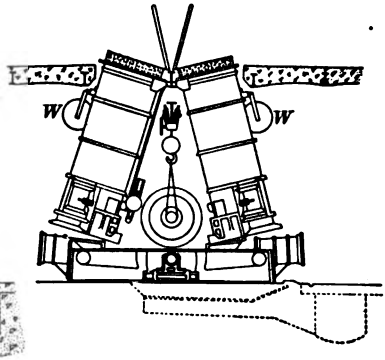

FIG. 22.

of magazine grinder largely overcomes the tendency of the arching over the pockets, and it also simplifies the task of removing the stone, as the magazine sections are swung out on their hinges far enough to allow the stone to be hoisted and carried out between them, as shown in Fig. 22. *W* is a wheel that turns as the wood drops in the magazine; it is so calibrated that the number of turns records the number of cords used.

In this grinder no water sprays are introduced below and only one above the stone.

A general idea of the details of the bearings, foundations, casings, and wood magazines may be had from a study of the details shown in Fig. 20.

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54. Grindstones.—The principal physical properties of grind stones used on magazine grinders have been already described for hand-fed grinders. It has been found difficult to get from the average quarry sound sandstone that will finish up into a pulp-stone 62 inches in diameter with a 54 inch face. This is due to the laminated structure of the sandstone beds, and to the greater chance for natural defects in a large stone, as compared with one of half the width, such as is generally used on hand-fed grinders. It is also necessary for the quarry to market the larger number of small stones taken out incidental to preparing the large stones. The larger stone also is more difficult to season uniformly. In some mills using stones of this size, experiments were made in removing the grindstone from use when partially worn out, to allow it to undergo another seasoning period; but beneficial results were not obtained.

The grindstones used in magazine grinders have a conical projection on their sides, in place of the flat sides of stones used in hand-fed grinders.

55. Shafts and Flanges.—The general make up of the shaft and flanges of the magazine grinder is similar to that of the hand-fed grinder. The steel shafts are usually 10 inches in diameter, enlarged between the flanges to 14 inches. The steel flanges are conical in shape, the concave side fitting over the conical projection on the grindstone. The flanges are supported upon the shaft in a manner similar to that already described under hand-fed grinders.

This arrangement of connection between the stone and the flanges is required, in order to resist a side thrust of from twenty to forty tons when the pressure is released from one side, due to pocket filling.

The couplings used between the driving motors and grinders are usually of the flexible type. These are employed to reduce the effect of eccentricity, caused by small defects in shaft alinement, and to facilitate the starting up of the grindstones with the synchronous type of motor used to drive magazine grinders. The slack obtained when backing off in the coupling allows the motor to accumulate some momentum before the resisting load of the stones is encountered.

56. Pressure Water and Electric Governor System.—Fig. 23 gives a general arrangement of the pressure-water connections

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to the hydraulic cylinders, and of their relation to the electric governor and pressure-water supply.

When the pistons in the cylinders marked 1, 2, 3, 4, move toward the stones, the high-pressure water used is pumped from the water-supply tank 5 by means of the high-pressure centrifugal pump 6. The water passes through pipe line 8, which is connected with tank 9*a*, partially filled with air, which maintains constant pressure on the water line. The water then passes through hydraulic regulator valve 10, controlled by an electric governor. The governor is simply a small induction motor 11, connected by means of transformers 12 to the leads of the motor driving the

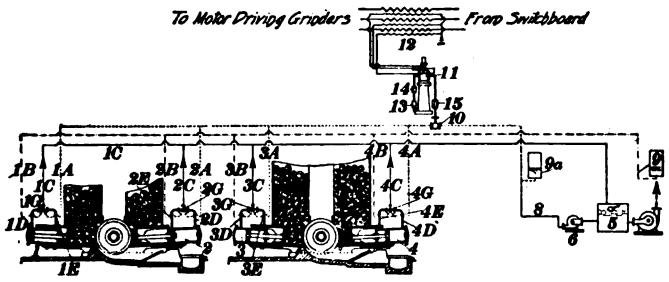

FIG. 23.

grinders. When a pocket is thrown off, thus tending to reduce the load on the motor by $\frac{1}{4}$, the change in flow of current through the grinder-motor leads causes the induction motor 11, to revolve through a small arc. This movement opens the hydraulic valve 10, and thus increases the pressure on the three pockets that are grinding, so that the same amount of power is absorbed by the three pockets as was used previously for the four. When the fourth pocket is again thrown on, a reverse action takes place, causing valve 10 to throttle the water, thus reducing the pressure on the grinder cylinders and maintaining a constant load on the grinder motor. A dashpot is shown at 13, which acts to steady the action of the governor. By varying the amounts of the weights 14 and 15, the pressure intensity in the grinder cylinders may be varied, causing an accompanying load adjustment on the grinder driving motor. Since low-pressure water is used for the rapid movement of pistons, the demand is intermittent; but when required, a large quantity of water is needed. Consequently, to maintain a desired pressure and to avoid surging, an air tank or accumulator 9 is placed in the pipe line.

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The water supplied to the hydraulic cylinders is controlled by means of the multiple-port, plug-type valves 1*G*, 2*G*, 3*G*, 4*G*. In Fig. 23, high-pressure water is passing through plug valve 1*G* and into the left end of cylinder through connection 1*D*. At the same time the water contained in the cylinder 1 to the right of the piston is passing back into the pump box 5, through connection 1*E*, plug valve 1*G*, and discharge line 1*C*. The piston in cylinder 2 is just at the end of a corresponding stroke. When the stroke is complete, the first movement of the plug valve 2*G* closes off the high-pressure water supply, 2*A*, opens the discharge for cylinder 2 by means of 2*D*, 2*G*, and 2*C*, shuts off discharge through 2*E*, and opens low-pressure water supply to the left end of the cylinder, by means of connection 2*B*, plug valve 2*G*, and connection 2*E*. After the piston in cylinder 2 has moved to its extreme right end of the stroke, thus opening the pocket, and the wood has fallen before the pressure foot (see Art. **52**), the plug valve is moved so that discharge from the left end of the cylinder opens for exhaust of water through 2*E*, valve 2*G*, and pipe 2*C*. At the same time, low-pressure water passes into the cylinder through 2*B*, 2*G*, and 2*D* until the pressure foot has set the wood against the stone. The next movement of the valve shuts off the low-pressure supply to the right end of the cylinder and connects that end of cylinder to high-pressure water supply through 2*A*, 2*G*, and 2*D*. This is the normal grinding connection.

57. Automatic Trip and Timing Device.—For the purpose of more easily regulating the load on the driving motor and the side pressure on grinder shafts, it is always advisable to have four cylinders connected with one timing device, which is so adjusted that not more than one cylinder can recharge at the same time. The adjusting of this device must be done at the mill; details of operation are as follows: Referring to Fig. 24, each cylinder is provided with a multiple-port regulating valve *A*, actuated by operating device *B*, both being mounted on one solid base casting. The valve is of the plug type, and controls both the high- and low-pressure water that operates the cylinders. The low-pressure inlet is at *C*, the high-pressure inlet is at *D*, and the discharge is at *E*, connection to front and back of grinder cylinder is at *F* and F_1, on back of column, respectively. F_1 is not shown in the figure.

Each operating device is driven by a belt from the grinder shaft to pulley *G*, which, operating through pinion *H*, drives crank

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gear V. This gear is connected by an adjustable connecting rod J to bell crank K, through which it imparts the necessary rocking motion to dog L. The gear M is driven through a train of gears from the crank gear V; this gear M is connected to crankshaft N, (which is extended, to connect with operating device on the second grinder); the crank on this crankshaft, through the adjustable connecting rod U, imparts the necessary motion through special bell crank O to trip dog P.

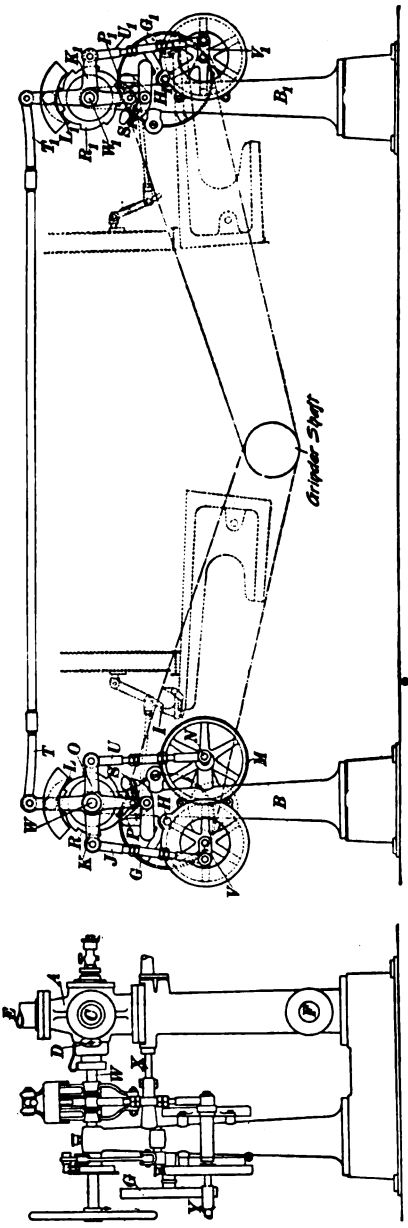

Fig. 24.

R is a ratchet wheel, which is keyed to the valve stem W. This ratchet has two teeth that are longer than the others. S is a disengaging foot, operated by a tripping arm X, which is set to regulate the forward stroke of pressure foot on grinder. When the pressure foot is traveling forward during the grinding operation, the dog L travels idly back and forth on one of the long teeth of ratchet wheel R, it not having sufficient travel to engage the next tooth. Trip dog P is also disengaged by foot S, in this operation; but when the pressure foot in the grinder pocket reaches the forward end of stroke, foot S is tripped by lug I, Fig. 20,

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allowing dog P to engage ratchet wheel R, and to move it forward far enough for dog L to engage the next tooth and advance ratchet wheel R, one notch, which admits low-pressure water to front of cylinder and returns the pressure foot; when the pressure foot has reached a determined point on the return stroke, the water is automatically shut off by a stroke regulating device. Dog L now engages the next tooth of R, thereby turning the plug valve so that all parts are closed, and gives time for wood to refill the pocket, when L engages the next tooth, low-pressure water is admitted to back of cylinder, and the wood is advanced to the stone. The next movement of the plug valve by the ratchet

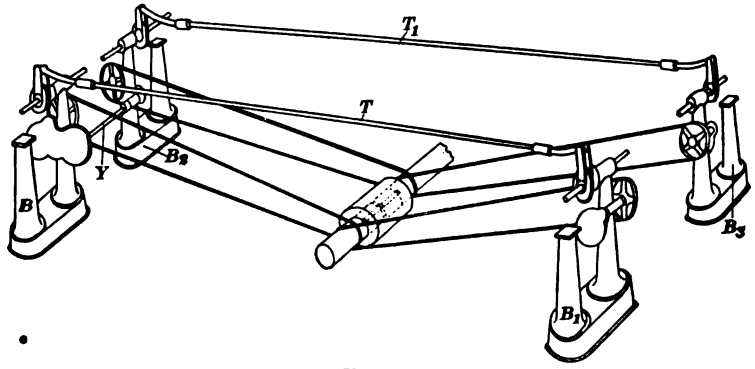

FIG. 25.

admits the high-pressure water for grinding, and it also brings the dog L onto the next long tooth, where it swings idly until the pressure foot has advanced to the determined point, when the cycle is repeated. It will be noted that one half-turn of the ratchet wheel R is sufficient to complete a cycle of operation.

The connecting rod T is used to connect up the timing device for the cylinder on the opposite side of the stone, as all timing devices are driven from one stand. The corresponding parts of the device for the other cylinder bear the same letters, with the subscript, as, L_1, T_1, etc. When two stones are driven by the same motor, as shown diagrammatically in Fig. 25, the master timing device B (same as B, Fig. 24) is connected to a device B_2, by means of shaft Y (Figs. 24 and 25).

The timing of pocket charging is set so that the pockets may charge at approximately equal time intervals in the order B, B_2, B_1, B_3 (Fig. 25), and so that only one pocket may be charging at

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a time. Although the time may arrive for a pocket to open, it will not do so until the trip-rod lever actually sets the lower dog P, P_1, etc., against the ratchet wheel. This sequence is controlled by the setting of the crank U, on devices B and B_2, and the adjustment of the rods T and T_1 so that the ratchet wheel is placed in position for pocket charging for each quarter revolution of the reducing gear M (Fig. 24).

58. Sharpening Device.—The sharpening device is shown at N, Fig. 20, and in detail in Fig. 26. This device is moved across

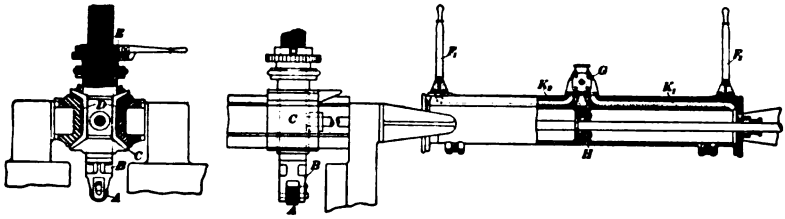

FIG. 26.

the face of the stone by means of a hydraulic cylinder, which projects out horizontally from between the wood magazines. The burr A is fastened in the holder B, similar to the hand-fed grinder sharpening device, except that it is in a vertical position. The burr carriage C is supported on two ways D, and the intensity of pressure of the burr against the grindstone is controlled by manual adjustment device E, on top of the burr carriage. The travel of the carriage is controlled by levers F_1 and F_2, which operate the valve G. With the levers as shown, the piston H is at rest. By opening the port K_1 to pressure-water inlet, the piston will move to the left, and the burr carriage with it, while water will be discharged through port K_2 from the cylinder. The two levers enable the operator to stand close to the stone he is dressing. The apparatus can also be applied to a single stone. During sharpening with this apparatus, the stone's surface may be thoroughly cleaned by means of shower pipes located just below the burr carriage ways.

59. Grindstone Pit.—With the automatic feed of wood and the complete enclosure of the stone, it is practicable to run the stock in the grinder pits thinner than is possible on hand-fed grinders, without causing much splashing and loss of pulp. Otherwise, the general design of the grindstone pits is similar in the two types.

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THE MECHANICAL-PULP MILL

CONTROLLING FACTORS IN MANUFACTURING

PRELIMINARY CONSIDERATIONS

60. Wood Supply.—Since the mechanical process of pulp manufacture simply changes the form of the wood, it is very natural that the first controlling factor in the production of the pulp is the *wood supply.* It is true that mechanical pulp may be made from many different species of wood; but the pulp, after it is made, must be used. Up to the present time the quality of the pulp from various woods has confined the raw materials to the relatively small number of species of wood already mentioned. A discussion of the qualities of different species of wood for production of mechanical pulps will not be given here. For such information the reader is referred to U. S. Department of Agriculture Bulletin No. 343, where complete operating data and photomicrographs of mechanical pulp from various species of wood may be found.

It is easier to make a good grade of mechanical pulp from green wood than from seasoned wood. Pulp made from seasoned wood has a tendency to be soft[1] and does not felt as well as green wood. Decay also takes place in stored wood and has the effect of very materially reducing the strength, color, and yield. Pulp of a better quality may be made from dense or slow-grown woods.

61. Power.—In the changing of the form of wood from a solid stick of pulpwood, large amounts of power are required. With a given grinder installation, the maximum production will depend upon the maximum horsepower that can be delivered by the prime mover, within the limits of good practice for the other variables. For newsprint groundwood, the power necessary to produce 1 ton of pulp in 24 hours will vary from 55 h.p. to 75 h.p. For some of the tissues, manilas, and book papers, as much as 100 h.p. per ton of product is used.

Water power generated by hydraulic turbines has been adopted for almost universal use in the manufacture of mechanical pulp.

[1] Mechanical pulp is commonly called soft when in the form of a wet sheet (75% to 88% moisture) on paper machines, its strength is low. In most cases this is due to short fibers.

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This is because it is the cheapest power that is available in large quantities. It may be applied directly to the grinder shaft; or it may be first converted into electric power, and the grinders may then be driven by a motor.

The **power available** is, evidently, dependent upon three principal factors: (1) the volume of water available; (2) the effective head; (3) the efficiency of the turbine (in cases of electrically-driven grinders, the combined efficiencies of the turbine, motor, and miscellaneous equipment between the turbine and the grinders).

The general expression for the power available for mechanical-pulp manufacture from a given hydraulic turbine installation is:

$$\text{h.p.} = \frac{\eta Q h \times 62.4}{550} = 0.1135 \eta Q h$$

in which,

h.p. = total horsepower delivered to grinders.

Q = total volume of water passing through turbine from water above the dam (forebay) to the level of water below dam (tailrace), expressed in cubic feet per second.

h = Effective head measured as the difference between the level of water in the forebay and tailrace, in feet. (See h Fig. 41.)

η = Efficiency of the turbine delivering the power, which varies from 80% to 90% for well designed turbines operating under favorable conditions.

62. The volume of water available depends on the stream flow and storage facilities for supplying the requirements for operation during dry periods. To get this information requires careful investigation, the details of which may be found in some of the standard works on water-power engineering. A study of the foregoing equation will show that the available volume of water during periods of reduced stream flow should always be used under the maximum head possible. Under these conditions, the minimum volume of water is used for the production of a given amount of power.

The **effective head** may be reduced by an uncontrollable fall in the level of the water in the forebay during dry seasons or by a rise in the level of the water in the tailrace, in the periods of increased stream flow. In the latter case, the channel below the

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power units is not large enough to carry off the extra volume promptly, and the water backs up in the tailrace.

63. The theoretical amount of potential energy contained in the water in the forebay cannot be all delivered as power at the turbine shaft. This is due to losses, some of which are controllable and others which cannot be controlled. **The efficiency** of the

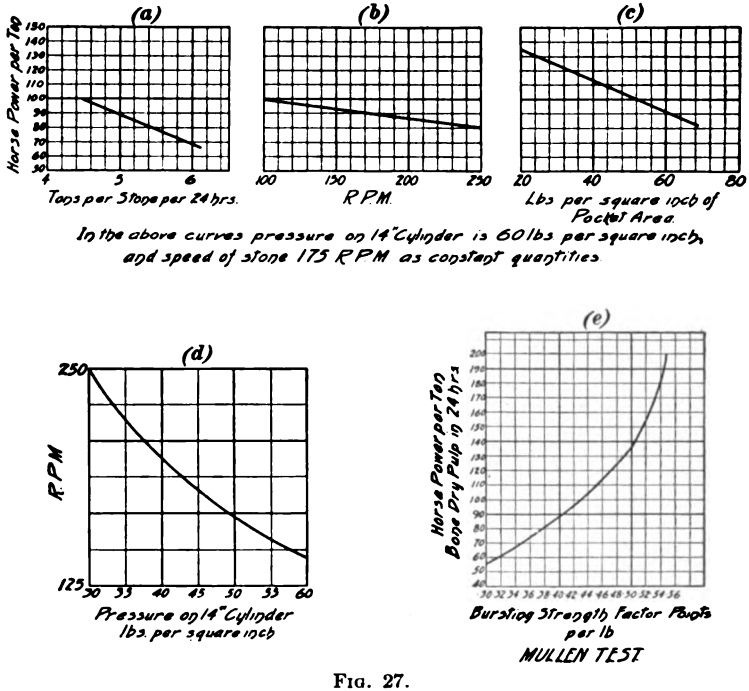
(a)
(b)
(c)
Horse Power per Ton
Tons per Stone per 24 hrs.
R.P.M.
Lbs per square inch of Pocket Area
In the above curves pressure on 14" Cylinder is 60 lbs per square inch, and speed of stone 175 R.P.M as constant quantities
(d)
R.P.M
Pressure on 14" Cylinder lbs. per square inch
(e)
Horse Power per Ton Bone Dry Pulp in 24 hrs
Bursting Strength Factor Points per lb
MULLEN TEST

FIG. 27.

turbine is a figure which shows the ratio of the amount of useful work performed by the turbine compared with the potential energy contained in the water in the forebay. It is a figure always less than one (1). For a discussion of turbine efficiencies the reader is referred to the literature on water power engineering.

With a certain available quantity of power for mechanical-pulp manufacture, the amount of production of a certain quality of pulp is quite definitely fixed. The curves[1] in Fig. 27 show this relation. They have been compiled from tests[2] which were pub-

[1] In plotting curves, as far as possible, only the factors plotted were allowed to vary.

[2] See also Art. 76.

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lished in U. S. Dept. of Agriculture Bulletin No. 343. Seasoned spruce wood 24 inches long was ground at a *practically constant horsepower input to the grinder*. The diameter of the grinder cylinder was 14 inches. With a constant horsepower input, the curves for this test, disregarding variation in woods, show:

(*a*) The power consumption per ton of pulp produced varies inversely with total tons produced in 24 hours.

(*b*) Power consumption per ton of pulp decreases as peripheral speed of stone increases. It must be borne in mind, however, that the quality of the pulp does not remain constant during this change.

(*c*) Power consumption per ton decreases as pressure of the wood against the stone increases. But, again, the quality of the pulp is affected.

(*d*) The pressure of the wood against the stone must decrease as the peripheral speed of the stone increases.

(*e*) The strength factor of paper made largely from mechanical pulp increases as the power consumption per ton of pulp increases. It is evident that this is true only within certain limits, since by using an unreasonably large amount of power per ton, such a fine powder would be produced, and by using too little power per ton, such coarse pulp would be obtained, as to be unsuitable for paper manufacture.

In general, the following is a summary of the facts brought out in the tests:

A given quality of pulp will require a fairly definite amount of power per ton. The quality varies most with the condition of the surface of the stone—less with differences in pressure and least with differences in the speed.

For the same power consumption, finer and shorter fibered pulp can be obtained when grinding at a higher pressure than is possible to obtain by using a sharper stone and lower pressure.

The yield of pulp per cord varies directly with the bone-dry weight per cubic foot of wood used.

TREATMENT AND OPERATION OF GRINDSTONES

64. Selection of Grindstones.—The ideal grindstone would be one in which the grit particles are sub-angular in form, embedded in a binder of softer material, which would wear away at such a rate that the grit of the stone would always be exposed to the

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extent required for the kind of pulp being made; the stone's surface would be of uniform hardness and strength; the physical make-up would be free from division planes, sand holes, flakes of mica, and other foreign materials. Unfortunately, the details included in the specifications covering the purchase of grindstones, at the present time, are not very specific. This is perhaps due to the lack of standardization in the required qualities, and to the willingness of the stone manufacturers to supply a sample stone for trial.

The grindstone is of such vital importance for the manufacture of a uniform quality of pulp that each one should be carefully examined and tested before being accepted for pulp manufacture. Quantitative information may be compiled on the fineness,[1] hardness, and toughness of the grindstone, and a physical examination of the stone will determine the amount of foreign materials present. (See Arts. **26–35.**)

65. The tests mentioned above serve as an indication of what to expect of a stone in service; and any trial stones that are used after this preliminary information is collected, will enable the pulp maker to decide more accurately on the kind of stone best suited to his requirements.

If, for example, it is desired to make a news grade of mechanical pulp, there is a certain hardness of stone and character of grit which will give the best results. If two stones are compared, which have the same size and character of grit, but the matrix in one of which is very hard, while in the other it is very soft, the soft stone usually wears away fast; in some cases, it may be almost self sharpening. Generally, this rapid wearing away of the stone causes it to become dull and require more frequent sharpening, to maintain quality and production. In the case of the hard stone, it is more difficult to get a good impression of the dressing burr upon the stone's surface; but when the impression is made, the stone usually requires less frequent sharpening. The sharp edges of the exposed grit of the hard stone sometimes cause a cutting action on the pulpwood stick; this may reduce the quality of the stock made to the point where it is necessary to smooth off the sharp edges with a brick, and, in some cases, it may be necessary to dress the stone.

[1] Refer to Canadian Department of Mines Bulletin No. 19 or to Pulp and Paper Magazine, Vol. XV, p. 1085 (1917).

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66. In Art. **65,** it is assumed that the size and shape of the grit particles were satisfactory for the grade of pulp made. If the average size of the grit were finer than required, to get the quantity of production desired from the grindstone, the grindstone would have to be sharpened hard frequently, and the quality of pulp made would vary accordingly.

Too frequent sharpening of the stone has a tendency to keep the stock free and stubby, which causes difficulties on the paper machine.

The selection of the grindstone, therefore, becomes a controlling factor from the standpoints of both quality and efficiency. In other words, the specifications of the best stone for the pulp to be made can be determined only by trial; they should be made to conform as nearly as possible to the standard.

67. Preparation of Surface of Stone.—After the selection of the proper stone for the quality of the pulp to be made, the surface must be prepared with a suitable **burr** or **bush roll,** which rotates in contact with the surface of the stone. The idea of this treatment is to expose the grit above the binding material by removing some of the latter, and, at the same time, to form small channels in the stone surface. The fiber, after being ground off, remains in the grooves, protected from re-grinding, until it is washed from the stone's surface by means of the shower pipe, which is located at the back of the stone.

The selection and use of the right burr to produce a pulp for a particular grade of paper is influenced by the quality of pulp required and, largely, by the particular individual who is in charge of the pulp making. It is true that practically the same results may be obtained from two different burrs; but, at the present time, there is no entirely satisfactory means available of knowing exactly how the two stocks thus produced differ. It is the lack of this information that leads to differences of opinion among pulp makers. In the following discussion of the practice of burring stones, it will be assumed that the other variables not here considered are constant, so that any change produced in the pulp will be due to a variation in the type of the burr that is used on the stones.

68. The three different types of apparatus used for carrying the burrs during the burring operation were described in Arts. **44–46.**

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When the burr is carried in a hand-operated stick, see Fig. 15, the amount of sharpening may be varied to suit the operator, according to the pressure and speed at which the burr is passed over the stone. This method has the disadvantage of producing an uneven pattern on the surface, and of wearing the grindstone more in the soft spots and less in the hard spots; in a short time, this causes the grinding surface of the stone to become irregular. The eccentricity of the stone on the shaft has the effect of tearing into the pulpwood at each revolution, producing a shivey stock. It is necessary, therefore, whenever the stone becomes unevenly worn, to restore it to the shape of a true circular cylinder. This is carried out by passing a coarse burr repeatedly over its surface, by means of one of the other two dressing devices.

69. A burr carried on a hand-operated stick is used most for **dulling,** or what is called **knocking back,** the surface of grindstones that have been given too severe a treatment with one of the other sharpening devices. The surface of the burr used for this treatment is much smoother than the type of burr used for sharpening, and it has the effect of knocking off the high spots and smoothing up the stone's surface. Sometimes, a hard-burned brick, mounted on the end of a hand-operated stick, is used to do this work. The brick does not rotate, but simply rubs against the stone's surface.

With the mechanical- and hydraulic-dressing devices, the depth of cut or degree of dressing is varied by the operator, by the adjustment of the burr-feed carriage. The sharpness of the stone, the freeness of the stock, and the production, all increase with the pressure at which the burr is pressed against the stone.

70. For dressing the surface of the grindstones, there are four different types of burrs in use. They are: the thread burr; the straight burr; the diamond point burr; and the spiral burr. Combinations and variations of these are also frequently used in successive treatments. The quality of pulp produced by each stone is affected by the combination adopted.

For any type of burr used under the same conditions, a coarser burr (4 to 6 cut) will grind the greatest amount of wood at a minimum horsepower per ton of product; but the freeness of the pulp will be high for the coarse burr, and the waste will also be high. As the coarseness of the burr is decreased, the production and waste will decrease, and when a fine burr (12 cut) is used, the production will be low and temperature of grinding increased.

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71. The Thread Burr.—This burr resembles in appearance the threads on a large bolt. These burrs are graded according to the number of threads that they have to the inch of face; thus, a 6-cut burr has 6 threads to the inch, measured parallel to the axis.

Fig. 28 is a photograph of a **thread burr**; Fig. 29 shows segment of a grindstone, and it indicates the relation between the rotation of the grindstone, dressed with a thread burr, and that of

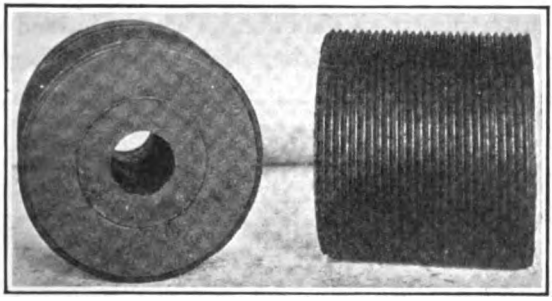

FIG. 28.

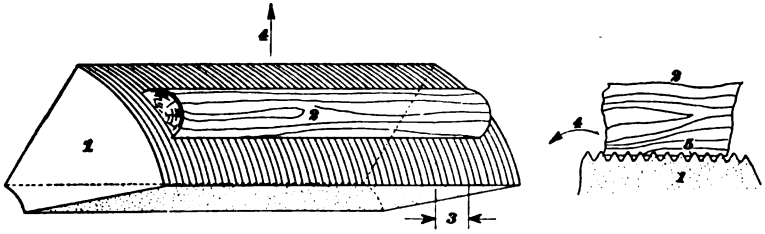

FIG. 29.

the pulpwood stick. Note that the burr rolls over the surface of the stone. In Fig. 29, 1 represents a segment of the grindstone; 2, the partially ground pulpwood stock; 3, number of thread marks per inch of width of stone (this corresponds with the **pitch, cut,** or **number** of burr used for dressing the stone); 4 represents the direction of rotation of the stone relative to the axis of pulpwood stick; 5 is a section of the surfaces in contact between the pulpwood and grindstone, showing the meshing of the grooves in the stone and wood.

It will be noted that the grooves cut in the surface of the stone are nearly perpendicular to the axis of the pulpwood being ground; also, that a fiber, after being separated from the stick, is subject to re-grinding in the exposed grooves shown at 5. The

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ridges of the stone, therefore, have a tendency to cut off and regrind the fiber. Consequently, the fiber made by the thread burr is short, and has a tendency to be stubby. The fiber loss in excess white water discharged from the mechanical-pulp system is large for this type of burr.

The thread burr is most successful when it is used lightly and often for dressing the stone's surface.

72. The Straight Burr.—With this type of burr, the grooves run parallel to the axis of the burr. They are graded according to the number of ridges that they have to the inch of periphery.

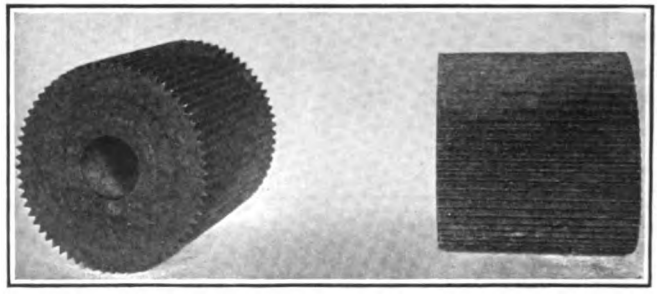

FIG. 30(*a*).

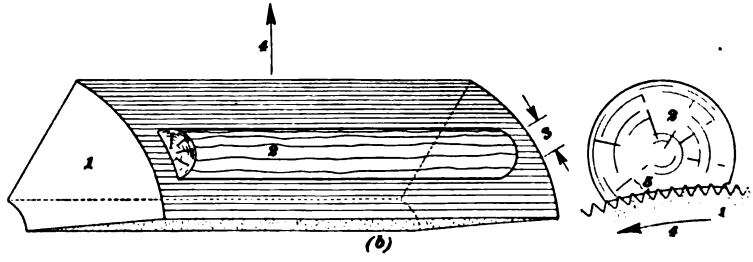

FIG. 30(*b*).

Fig. 30 (*a*) is a photograph of a **straight-cut burr**; Fig. 30 (*b*) shows a segment of a grindstone, and it indicates the relation between the rotation of the grindstone, dressed with a straight-cut burr, and the pulpwood stick. 1 represents a segment of the grindstone; 2, the partially ground pulp-wood stick; 3, number of grooves per inch of periphery of stone, corresponding again with the *cut*, *number*, or *pitch* of burr used for sharpening the stone; 4, the direction of rotation of the stone relative to the axis of pulpwood stick; 5 is a section of the surfaces in contact between the pulpwood and grindstone, showing the grooves in which the

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fibers remain, protected from re-grinding, until washed from the surface of the stone by shower water, at each revolution.

With this type of burr, a long fiber is made, but the proportion of slivers or waste is high. The amount of slivers may be reduced by making the distance between the ridges of the burr smaller; or, in other words, by using a finer-cut burr.

73. The Spiral Burr.—With this type of burr, which should properly be called a **helical burr,** the grooves are cut at an angle to the axis of the burr. They are graded according to the number of ridges to the inch and their lead across the face of the burr.

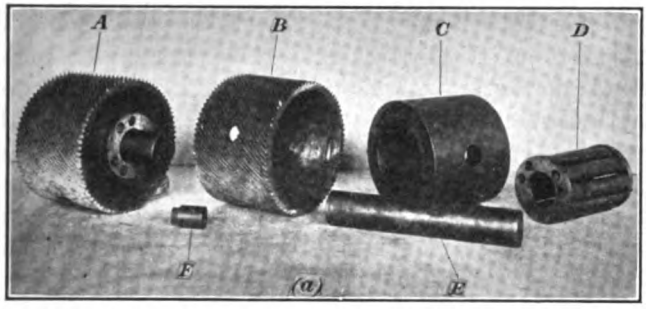

FIG. 31(*a*).

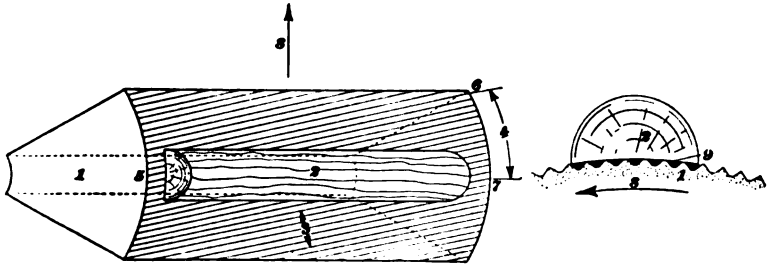

FIG. 31(*b*).

Fig. 31 (*a*) is a photograph of a **spiral burr** of the shell type, and shows the general assembly and knocked-down parts of the roller bearing and the mandrel used with a shell burr. *A* is the assembled parts; *B*, the burr; *C*, the liner; *D*, the roller bearing; *E*, the mandrel; *F*, the pin, which is slipped into place from inside the liner, and held in place by the roller bearing.

In Fig. 31 (*b*), 1 represents a segment of the grindstone; 2, a partially ground pulpwood stick; 3, the number of grooves per

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inch on stone, measured along a line perpendicular to direction of grooves, corresponding to the *number*, *cut*, or *pitch* of the burr. The lead of the spiral burr groove in passing across the stone's surface from 5 to 6 is represented by distance 4, measured along the periphery of the stone. The point 7 is located by a perpendicular 5–7 to face 6–7. The lead across the face of the grindstone is longer than the lead on the spiral burr, because of the difference in the width of the face of burr and grindstone. However, the lead of the burr is determined by the same method as that described above. The angle of the slope of the spiral markings is the same in both cases. 8 represents the direction of rotation of stone relative to the axis of the pulpwood stick; 9, shows a section of the surfaces in contact between pulpwood and grindstone surfaces. The fibers are removed from the surface by means of angular rubbing action. The darkened area represents fiber accumulations in grooves in the stone, where they are protected from re-grinding.

The spiral burr may be varied in design, from a thread burr as one extreme to a straight burr as the other extreme. In actual use, it results in a smaller production than the straight-cut burr of the same pitch; but, at the same time, the waste produced is less. As the lead of the burr is increased, up to a certain point, the pitch remaining constant, the length of the fiber and the amount of waste are decreased; but when this point is passed, the stock becomes stubby, and the waste again increases. With the same lead, the production decreases as the pitch, or number of teeth to the inch, increases.

If, for example, a stone were dressed with an 8-cut spiral burr with a 1¼-inch lead, and the stock made were too free for the paper machines, the stock could be slowed up by using an 8-cut spiral burr with a 2½-inch lead, or a 10-cut spiral with a 1¼-inch lead. So far as production is concerned, the coarser the burr, the greater the production.

74. The Diamond-Point Burr.—In this type of burr, the surface is made up of pyramids having square bases. It is really a thread burr and straight burr combined. These burrs are graded according to the number of diamond points which they have per square inch of surface; they usually have the same number of points per inch of face (*i.e.*, per inch parallel to the axis) and per inch of periphery. The *pitch*, *number*, or *cut* of the burr is designated in the same manner as for the thread or straight burr.

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Fig. 32 (*a*) is a photograph of a **diamond point burr,** and Fig. 32 (*b*) shows the details of contact between the surface of the stone and pulpwood stick. In Fig. 32 (*b*), 1 represents the grindstone segment; 2, the partially ground pulpwood stick; 3, the number of recesses cut by diamond points per inch of stone surface; 4, the number of recesses cut by diamond points per inch of periphery

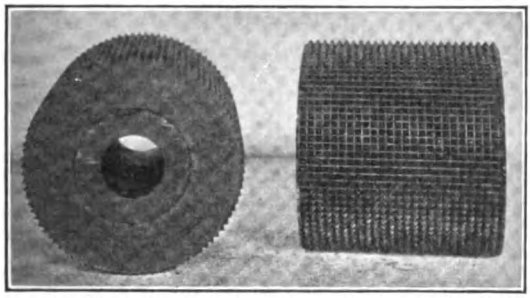

Fig. 32(*a*).

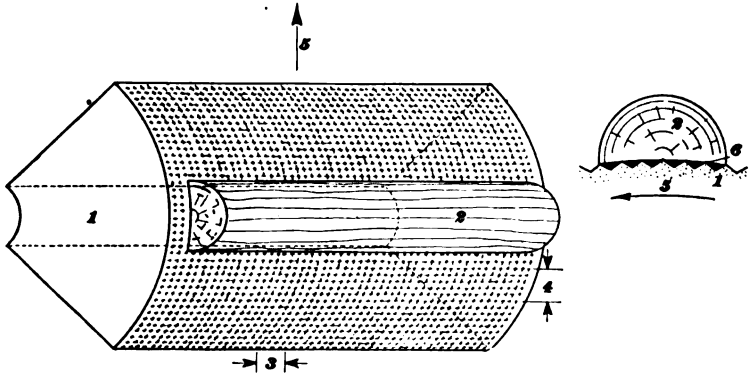

Fig. 32(*b*).

of stone; 5, the direction of rotation of the stone relative to axis of pulpwood stick; 6 is a section of the surfaces in contact between pulpwood and grindstone. The darkened area represents the fiber accumulations, protected from re-grinding in small pockets cut in stone's surface.

With this type of burr, the production and amount of waste depend upon the coarseness of the burr, or number of diamond points per square inch of surface. For the same coarseness of burr, it makes less waste in sliver than the straight burr and less

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white-water waste than the thread burr. The fibers made with a diamond burr have a tendency to be short and chunky.

75. Special Burrs.—There are several companies that have devoted much study to the practical side of the requirements of burrs for preparing the surface of grindstones. In one patented process, the combination marks of a coarse straight-cut burr and a fine-cut spiral burr are used. In Fig. 33, *A* shows a sketch of

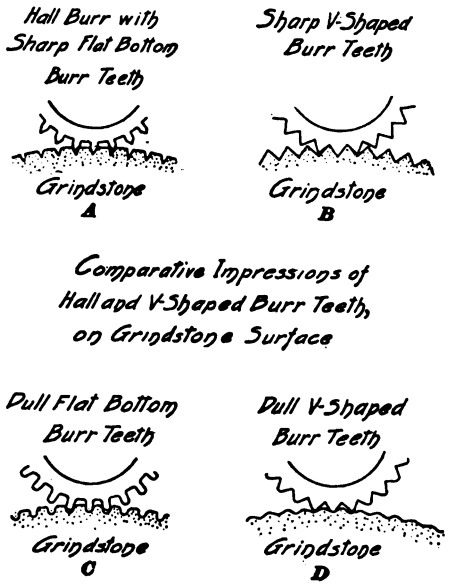

FIG. 33.

the shape of the flat-bottom tooth of this straight-cut burr compared with the V-shaped teeth (shown at *B*) commonly used for grindstone burrs. With the flat-bottom teeth, it is apparent that the effective grinding surface of the stone is somewhat larger than with the V-shaped teeth for the same cut burr; this is caused by the straight sides and thinner teeth of the special burrs. There is also an advantage with this shape of burr tooth, that a burr may be re-used more often and still maintain a substantially constant area of grinding surface on the grindstone. In the case of the V-shaped tooth, the dulling of the points makes a material variation in the surface of the stone in the dressed condition. This may be understood after a study of *C* and *D*, Fig. 33.

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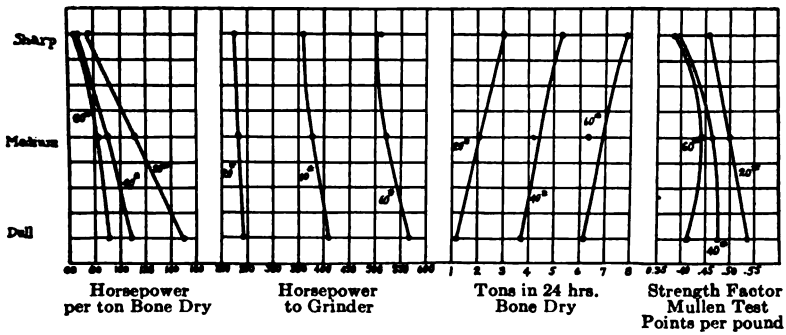
76. Experimental Results.—The curves in Fig. 34(*a*) are reproduced from the series of tests published in U. S. Dept. of Agriculture Bulletin No. 343. Seasoned spruce wood, 24 inches long, was ground at a *constant speed of* 225 *r.p.m.* In the curves given, the sharp stone was burred with a 6-cut spiral burr, with a 1½-inch lead; the medium stone had the impression of an 8-cut diamond point burr on its surface, and the dull stone had a 3-cut, straight-cut burr marked over a 12-cut, 1½-inch lead spiral burr. The slopes of the curves are therefore, not exactly as they would



Relation of Power Consumption, Production and Strength Factor with Sharpness of Stone at 225 R.P.M. and Various Cylinder Pressures

FIG. 34(*a*).

have been if the same burr mark was on the stone for each condition of the stone's surface. The designs of the different burrs used for varying sharpness of stones cause a magnifying of the effect of sharpness variation. These curves, however, show the following features:

(*a*) The power consumption per ton of pulp and power to grinder vary inversely as the sharpness of the stone's surface.

(*b*) The higher the pressure used, the less the condition of the stone's surface affects the power consumption per ton of pulp.

(*c*) All curves for power used per ton tend to converge at about 50 h.p. to the ton,[1] indicating that this is the minimum horsepower at which mechanical pulp of a certain quality may be made under the conditions of the test, regardless of pressure and condition of stone's surface.

[1]The point of convergence may be found approximately by extending the three curves at the left (assuming them to be right lines for the extended parts) and locating the points of intersection, which practically coincide in a single point. This point will be about half a space to the left of vertical line 60, and a vertical line drawn through this point will represent 50 h. p.

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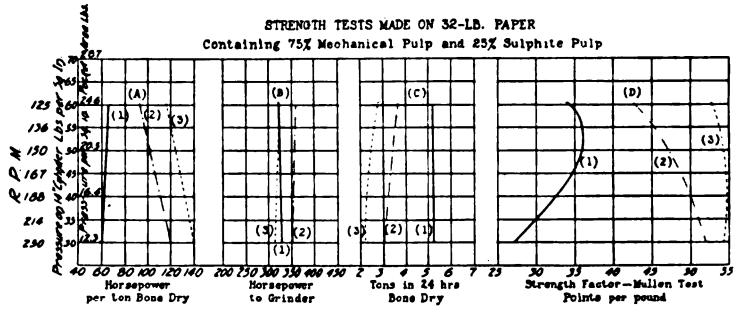
(*d*) The production of pulp in bone-dry tons per 24 hours increases directly with the sharpness of the stone, and at practically the same rate for all grinder pressures.

(*e*) The strength of the pulp made decreases with the increase in sharpness of the stone. (At 60 pounds pressure, the maximum strength is obtained with the medium stone.)

Fig. 34 (*b*) shows a set of curves made up from data for different degrees of stone sharpness, and the use of different burrs, with *constant input of power to the grinder*. For example, for a sharp



Relation to Pressure and Speed of Power per ton (A), Production (C), and Strength (D) for Grinders
Operated at Constant Power Input and Variations in Total Horsepower (B) Using Types of Burr as Below
(1) Straight cut No. 3 and Spiral Burr 12-cut 1½" Lead, Freshly Dressed.
(2) Straight cut No. 3 and Spiral Burr 12-cut 1½" Lead, Partially Dull.
(3) Straight cut No. 3 and Spiral Burr 10-cut 1½" Lead, Partially Dull.
At Constant Horsepower to Grinder—Relation of Power per Ton, Production, and Strength to Pressure and Speed
(1) Runs— 32— 38—Straight cut No. 3 and Spiral Burr—12-cut 1½" Lead, Freshly Dressed.
(2) Runs— 28— 31—Straight cut No. 3 and Spiral Burr—12-cut 1½" Lead, Partially Dull.
(3) Runs—160—168—Straight cut No. 3 and Spiral Burr—10-cut 1½" Lead, Partially Dull.

FIG. 34(*b*).

stone dressed with a 3-cut, straight burr, and a 12-cut spiral burr with a 1½" lead, the curves show the effect of the factors mentioned on (*A*) horsepower consumed per ton of pulp, (*B*) total horsepower per grinder, (*C*) production per grinder, (*D*) bursting strength of paper containing 75% of this pulp. The vertical scale is common to all the curves, and, in itself, shows the different combinations of pressure and speed that may be employed to absorb the power furnished to the grinder. It is evident that high speeds are only possible at low pressures on the wood, and that high pressures result in low speed.

Curves (*B*) show the practically constant supply of power per grinder for each character of stone surface.

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Curves marked (1) are for a stone, freshly dressed with a No. 3, straight-cut, burr and a 12-cut, 1½″ lead, spiral burr.

Curves marked (2) are for a stone dressed as for (1), but partially dull.

Curves marked (3) are for a partially dull stone, dressed with a No. 3, straight cut, and a 10-cut, 1½″ lead, spiral burr.

Looking at the curves marked (1), it is seen that, with 330 h.p. (See *B*) supplied to the grinder and a pressure of 12.3 lb. per sq. in. pocket area, the speed was 250 r.p.m.; from (*A*), the power consumed per ton of pulp was 60 h.p.; from (*C*), the production per grinder was 5.2 tons per 24 hours; and from (*D*), the bursting strength (Mullen Test) of the paper—32 lb. news, made of 75% mechanical and 25% sulphite pulp—was .27 points per lb. (= lb. per sq. in. ÷ lb. per ream).

Similarly, for a stone dressed as under (2), operating at the same speed and pocket pressure, and a power input (*B*) of 352 h.p. to the grinder, the curves show (*A*), a power consumption per ton of 120 h.p.; (*C*), a production of 3 tons per 24 hours; and (*D*), a strength test of .52 points per lb. Thus, while the production fell off 40%, the strength and the power consumption per ton nearly doubled. These curves show the effect of dulling the stone. By comparing curves (3) with (1) and (2), one is able to see the effect of changing sharpness and changing burr.

By following each curve upward, the effect of changing the pocket pressure can be seen in the change of other factors. Careful analysis of these curves will be of assistance to the reader in the consideration and interpretation of the manufacturing methods for different grades of mechanical pulp to be considered further on.

77. Pressure of Wood Against Grindstone.—For a constant horsepower input to the grinder, the pressure of the wood against the grindstone influences the speed of the grindstone (except when driven by a synchronous motor), and also the quality and quantity of pulp made. The following formula, which is a modification of the Prony-brake formula, serves to illustrate the relation of the mechanical variables affecting grinder operation.

$$\text{h.p.} = \frac{\pi dN(\mu W)}{33000 \times 12} = .000007933dN(\mu W)$$

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h.p. = total horsepower delivered to the grinder.
π = 3.1416
d = diameter of stone in inches.
N = r.p.m. made by the stone.
μW = force opposing the rotation of stone, in pounds.
W = total thrust, in pounds, of the pressure foot against the stone's surface, less small losses due to friction and lateral pressure.
μ = the coefficient of friction between the wood and the stone's surface for the pressure, speed, and condition of wood as to age and moisture content.

The product $\frac{\pi dN}{12}$ gives the lineal velocity in feet per minute of any point on the stone's surface. Since the diameter of the stone wears down very slowly, it may be assumed to be constant, for the sake of illustration, leaving N the only variable. If it also be assumed that conditions affecting the value of μ are constant or vary only a small amount, the force opposing rotation,

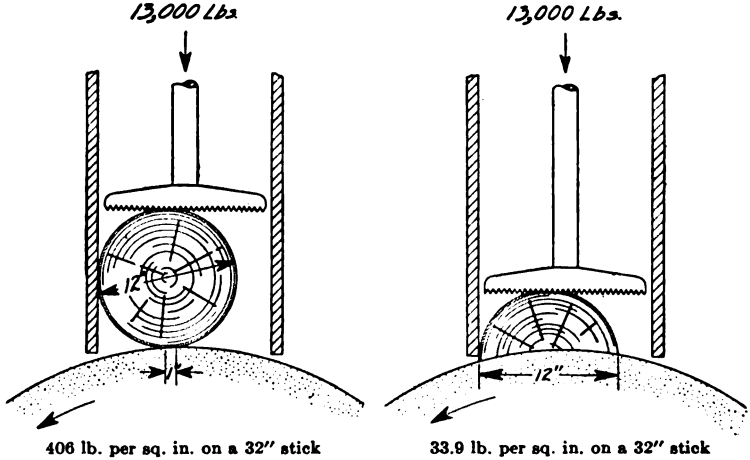

FIG. 35.—Pressure Variation of Wood against Stone During Grinding of 12" Stick of Pulp Wood.

μW, will vary directly with pressure in the hydraulic cylinder. An examination of the formula will show, then, that for a constant horsepower input, with other variables constant, the higher the pressure carried in the hydraulic cylinders, the less is the speed of rotation.

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78. Pressure Variation.—Suppose that Fig. 35 represents a pulpwood stick 12 inches in diameter and 32 inches long. The total pressure that may be exerted by the hydraulic cylinder will be taken at 6½ tons (13,000 pounds). When the pressure foot begins to force the wood against the stone, there are two convex surfaces in contact with each other; and if the time be taken when there is contact along 1 inch of periphery, the total area of wood

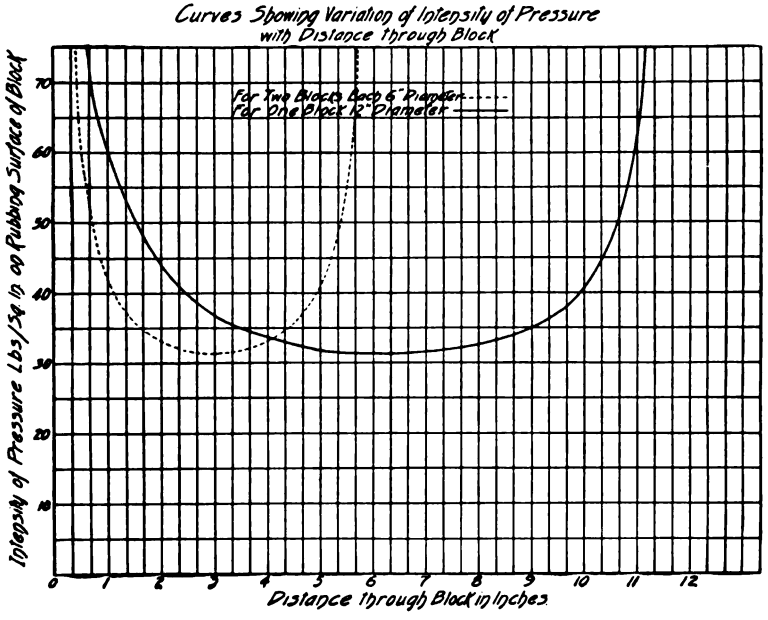

FIG. 36.

carrying the 6½ tons is 32 square inches. The intensity of pressure of wood against the stone is then 13,000 ÷ 32 = 406 pounds per square inch. When the stick is ground half-way through, there are 32 × 12 = 384 square inches of wood surface in contact with the stone, and the intensity of contact is 13,000 ÷ 384 = 33.9 pounds per square inch.

Fig. 36 shows graphically, the variation of the intensity of pressure, with surface of contact for the 12-inch stick, described above, and for two 6-inch sticks placed in a similar pocket. It is evident, therefore, that the variation in pressure between the wood and the grindstone is always great, when using round sticks, and the pulp that is made is an average of that produced

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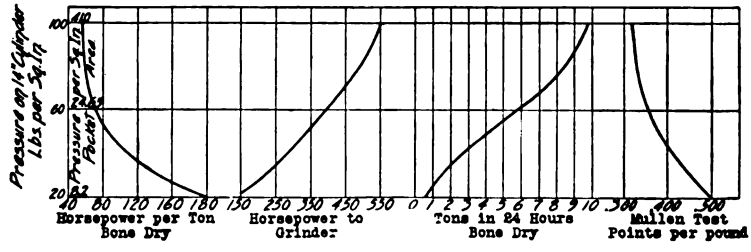
under these varying pressure conditions. The large logs on the Pacific Coast are first sawed into timbers, usually 8 in. square, and nearly constant pressure conditions are thus obtained.

There is a very wide variation in the pressures used in commercial practice. In some localities, there is a shortage of power and a reference to the formula of Art. **77** will show that if the speed is to be maintained constant, the pressure must be increased or decreased with the variation in power available. When there is a surplus of power, the intensity of pressure used is adjusted in accordance with the quality of pulp to be made. A high pressure with a sharp stone gives a very free stock, while a high pressure with a dull stone gives a slower stock, but the rate of production is lower.

79. Experimental Results.—Fig. 37 is a reproduction from J. H. Thickens' work, "The Grinding of Spruce for Mechanical Pulp."[1] The same equipment was used as is illustrated in Fig. 5. The speed of the stone was 225 r.p.m., but only two of the three pockets of grinders were used. The stone was dressed with a 3-cut, straight burr, and 12-cut, spiral burr, with a 1½-inch lead. The curves of this particular test show:

(*a*) The horsepower to the grinder increases directly with the pressure of grinding.


Pressure on 14" Cylinder Lbs. per Sq. In.
Pressure per Sq. In. Pocket Area
100
60
20
40
24.65
8.2
0 40 80 120 160 180 150 250 350 450 550 0 1 2 3 4 5 6 7 8 9 10 300 400 500
Horsepower per Ton Bone Dry
Horsepower to Grinder
Tons in 24 Hours Bone Dry
Mullen Test Points per pound

Relation of Power Consumption, Rate of Production, and Strength to Pressure at 225 r.p.m., 2 Pockets Grinding. (Strength Test Taken on Paper Containing 75% Mechanical Pulp and 25% Sulphite Pulp)

FIG. 37.

(*b*) The horsepower consumption per ton decreases with increase in pressure. Three times as much power per ton is used at 8.2 lb. per sq. in. pocket pressure as at 24.65 lb. per sq. in. pocket pressure.

(*c*) The production of bone-dry pulp in tons per 24 hours increases directly with increase in pressure. At 16.4 lb. per

[1] U. S. Department of Agriculture Bulletin No. 127.

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sq. in. pocket pressure and 275 h.p. to grinder, 2.72 tons were produced. With 41 lb. per sq. in. pocket pressure and 550 h.p. to grinder, the production is 9.75 tons, showing that with 2½ times the pressure by doubling the horsepower to the grinder, the production is increased more than three-fold, in this case; but this result does not constitute a general rule, as quality is not here considered.

(*d*) The strength of pulp is best at low intensities of pressure. (But further investigation is necessary in order to establish the exact limits of pressure and quality variation.)

80. Speed of Stone.—The peripheral speed of the stone is the rate that a point on the outside edge of the stone travels, usually expressed in feet per minute. It is represented by the product $\frac{\pi dN}{12}$ in the equation of Art. **77.** Thus, the peripheral speed of a 54-inch stone at 240 r.p.m. is $\frac{3.1416 \times 54 \times 240}{12} = 3393$ ft. per min.

In the case of a grindstone 54 inches in diameter, the periphery of the stone is $3.1416 \times 54 \div 12 = 14.14$ feet. One revolution of the stone is equivalent to 14.14 feet of stone planing over the surface of the pulpwood stick. If 0.0025 inch be planed or rubbed from the stick of wood at each revolution, at a speed of 240 r.p.m. of the stone, the stick would be ground down at the rate of $0.0025 \times 240 = 0.6$ inch per minute. On the other hand, if the stone has worn down to 40 inches in diameter, the periphery will be 10.47 feet; and at the same speed of 240 r.p.m., there would be only $(10.47 \div 14.14) \times 100 = 74\%$ of the grinding down action on the wood, and the production of pulp would vary accordingly. If it be desired to get the same peripheral speed, or same number of feet of stone rubbing against the wood per minute, it would be necessary to run the 40-inch diameter stone at $240 \times \frac{54}{40} = 324$ r.p.m.

The limiting mechanical factors governing the speed of grindstones are: (1) the mechanical strength of the stone; (2) the method used for clamping the stones on the shafts. The general practice for safe operation is to keep the peripheral speed of the stone below 3500 feet per minute. So far as the quality of the pulp is concerned, the more uniform the speed of the stone the more uniform is the quality of pulp. This is a reasonable con-

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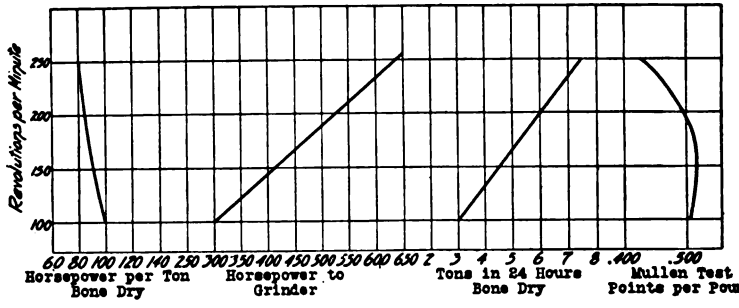
clusion, and it has been demonstrated in actual practice and experimentally.

It is not always economical to decide upon a certain speed for operating grindstones by duplication of a successful speed at another mill. The hydraulic turbines, which are usually direct connected to grinders, have certain characteristics that should be carefully considered before fixing the speed of operation. This will be referred to later, in more detail.

Fig. 38 is a reproduction from Thickens' experiments on variation in peripheral speed. These particular curves show:

(*a*) The horsepower to the grinder increases with the speed of stone.


Revolutions per Minute
250
200
150
100
60 80 100 120 140 250 300 350 400 450 500 550 600 650 2 3 4 5 6 7 8 .400 .500
Horsepower per Ton Bone Dry
Horsepower to Grinder
Tons in 24 Hours Bone Dry
Mullen Test Points per Pound

Relation of Power Consumption, Rate of Production, and Strength to Speed at 60 lb. Cylinder Pressure Stone, Burred with Straight Cut 3 to inch and Spiral Cut 12 to inch.

FIG. 38.

(*b*) The horsepower consumption per ton decreases with increase in speed. About ¼ less power per ton is used at 250 r.p.m. than at 100 r.p.m.

(*c*) The production in tons of bone-dry pulp per 24 hours increases with the speed of rotation. With 100 r.p.m. and 300 h.p. to grinder, the production is 3 tons, with 250 r.p.m. and 640 h.p. to grinder, the production is 7.5 tons. This shows that by increasing the horsepower to grinder 2.13 times, and the speed of rotation 2.5 times, the production increases 2.5 times.

(*d*) The quality of pulp made was best at slow speeds of rotation; but in view of the comparatively small number of tests made, this cannot be accepted as always holding true.

It is considered good practice not to operate stones at the maximum peripheral speeds that safety permits, and to control the quality of the pulp by varying other factors.

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81. Temperature of Grinding.—The effect of temperature enters in two ways: (*a*) the actual temperature at which grinding occurs; (*b*) the effect of atmospheric temperature on the grinding conditions.

There are two general methods used in the manufacture of mechanical pulp, so far as temperature on the grindstone is concerned: (1) the hot grinding process; (2) the cold grinding process. There is no exact division point between the two methods.

On this continent, the so-called hot grinding process is in use. In connection with this method, the volume of cooling water used is so regulated that the temperature of the pulp in the grinder pits is from 130° to 190° F. With a given stone surface, an increase in temperature has the effect of increasing the rate of grinding; but at the same time, the stock that is made contains more sliver, and it increases in freeness. The cold grinding process is in more common use in Europe. In this process, the volume of water used is larger than for the hot-grinding process, and the pulp in the grinder pits is lower in consistency; the rate of production is also lower. Hot-ground pulp is usually slower than cold-ground pulp, and it makes up into a paper of better quality.

The control of temperature variation on the stone depends upon the temperature and volume of water used, either sprayed against the stone or into the grinder pit. This water, in addition to cooling and washing the surface of the stone, acts somewhat similar to a lubricant between the surface of the stone and wood.

82. Practically all mills manufacturing mechanical pulp have seasonal variations in temperature of their water supply; and during the summer months, there is also less chance for dissipating the heat that is given to the system by the grinders. The result is a gradual increase in temperature of the stock and white-water system. It would, therefore, be advantageous, in the summer, to cool the shower water by spray evaporation, which, at the same time, would tend to remove the excess water employed. The capacity and cost of such equipment to accomplish a satisfactory temperature reduction has prevented methods of this kind from coming into more general use.

To prevent the rise in temperature of the system, it is common practice to waste large amounts of the warmed-up white water, replacing it with fresh water of a lower temperature. In the description of the freeness tester, Art. **14**, Fig. 3, the importance of

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viscosity variation of water with temperature was pointed out. Consequently, the addition of the cooler water should have the effect of slowing up the stock used for paper making. This cool water, upon being added to the system, must replace some of the white water that is in circulation through system, causing a loss of fiber or filler. The loss of this fiber, which contains the shorter pieces, has the effect of freeing up the stock in the system, thus leaving the final stock suspension freer or slower than it would be without the addition of fresh water, depending on the temperature and volume of the fresh water added and the effect that the fiber loss produces.

83. During the summer months, pitch usually accumulates on parts of the paper machines, which causes considerable trouble, and the result is a low efficiency of machine operation. The quantity of pitch deposit also seems to be closely related to the temperature of the stock. By the substitution of fresh water for the white water, the amount of pitch deposit is reduced, and, at the same time, a continuous discharge of water from the system is provided. This practice is a method for relieving the pitch trouble, but it is the cause of considerable loss in fiber.

The immersion in water of wood taken from water storage, especially in warm weather, and immediate grinding after barking, has a tendency to make this wood softer than that ordinarily used in winter, or after long storage in a pile.

84. During the warm months of the year, a change to a finer-cut burr than the one used during the winter operations is usually made. The object of this change is to offset the freeing up of the stock, due to: (*a*) increase in temperature of water; (*b*) loss in fine fiber from the system; and (*c*) the more drastic action that takes place between the stone's surface and the softened-up wood. Fig. 39 shows the freeing up of the stock produced from river-driven wood compared with storage (block-pile) wood at various rates of production, all reduced to standard test conditions of temperature and consistency. During summer operation, the effective length of the fiber must be shortened up, in order to maintain a stock freeness similar to that of winter operations. The finer-cut burr, as mentioned above, accomplishes this result.

85. The seasonal change in burr coarseness, just referred to, may be taken as an example of some of the variables that must be considered in the manufacture of mechanical pulp. Because of

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lack of accurate information on the variation in fiber length and uniformity (see Art. **16**) of mechanical pulps, these remarks are necessarily qualitative.

Suppose that, for winter conditions of operation, an 8-cut, spiral burr were used with a 3-inch lead, and that the wood ground came from the block pile. Under these conditions, assume a stock made up of a certain size variation, with enough filler to

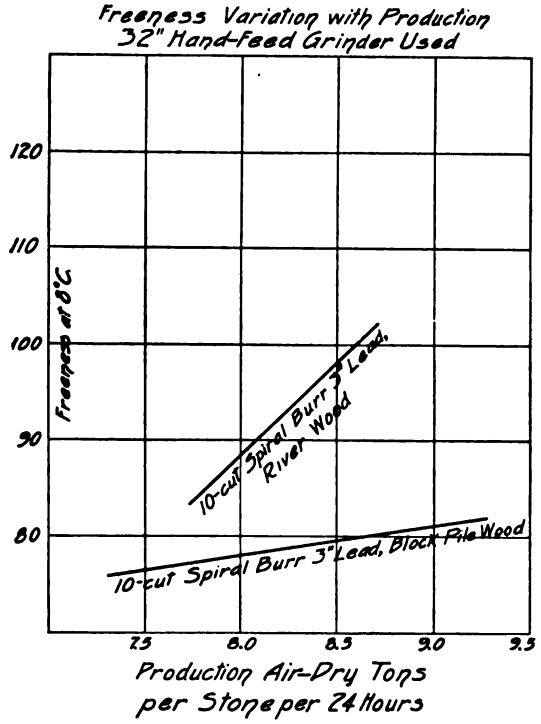

FIG. 39.

close up the sheet of paper and give the desired freeness of stock for paper machines. If the peripheral speed, horsepower input per ton, and hardness of wood remained constant, and the coarseness of the burr were decreased, the production would decrease. The effective length, as well as the uniformity coefficient of the pulp, would also change, resulting in a slower stock containing a larger percentage of filler (smaller fibers). If the coarseness of the burr were increased, the opposite effect would be produced. On the other hand, if the 8-cut, 3-inch lead burr were in use, and

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the wood changed from block-pile wood to river-driven wood, which means a softer wood, there would be a freeing up of the stock, due to two principal causes: (*a*) The lengthening out of the fiber and increase in its coarseness, caused by the more drastic action of the particular grindstone surface upon the softer wood; (*b*) the decrease in the amount of filler in the stock, caused by a more flexible and more easily separated fiber in the pulpwood stick.

The work of the pulp maker is to maintain a uniform quality of stock by the proper adjustment of the controllable variables, to meet the changes in raw materials and natural conditions, over which he has little or no control.

QUESTIONS

1. If a stone 50 inches in diameter runs at 250 r.p.m. (*a*) what is the peripheral speed in feet per minute? (*b*) How much faster does the surface of a 60-inch stone travel, if it runs at 220 r.p.m.? *Ans.* { (*a*) 3272.5 ft. (*b*) 183.3 ft.
2. What are the advantages in operating a magazine grinder?
3. What factors influence (*a*) the power consumption per grinder (any type)? (*b*) the power consumption per ton of production?
4. How does the softness or hardness of a stone affect the dressing of it?
5. What is a burr, and what is it used for?
6. What is meant by "knocking back" a stone surface? why is it done?
7. How does pressure of wood on the stone affect (*a*) power consumption? (*b*) yield of pulp? (*c*) speed of stone?

MECHANICAL-PULP MILL LAYOUT

86. Diagram of Layout.—Fig. 40 shows in diagrammatic form the layout of the equipment in a typical mechanical-pulp mill. In this layout, the stock is pumped from the grinders to the screening system, which is located at such an elevation above the grinder room that the returned white water is at sufficient pressure for use at the grinder showers.

The pulpwood is delivered to the wood storage bins 2 by means of conveyor 1. The bottom section of the wood-storage bin connects with the water tank 3, by means of which the wood is floated to individual grinders for use. At 4, a wood measuring rack is shown; all the wood that is ground is measured by piling into standard racks, and the number of full racks ground is recorded as the consumption per grinder. A grinder is shown

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at 5. The pressure-water supply for the hydraulic cylinders of the grinder is shown connected at point 6. The volume of water required by pressure pumps is supplied from a pipe, which passes through the dam 7. In order to strain out some of the grit and other foreign materials carried in suspension in the water, the water is passed through a wire sieve 8, usually of 60-mesh to the inch, before entering the pump-well below the screen. The strained water is then pumped to grinders by means of centrifugal pump 9.

A pressure-reducing valve is located at 10, in the pipe line to the grinders. This valve reduces the pressure delivered by the

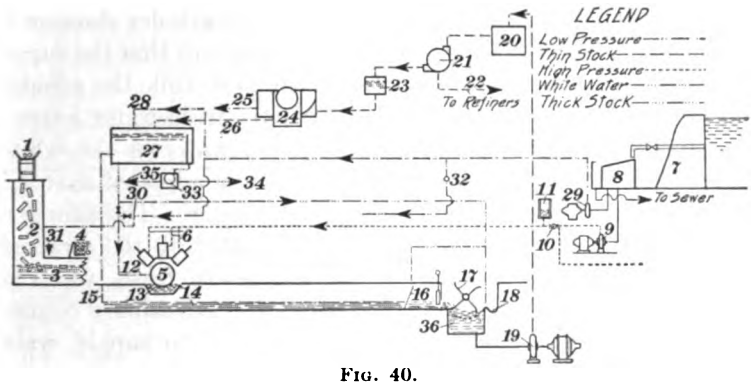

FIG. 40.

centrifugal pump to the pressure required in the grinder cylinders. There is also a large enclosed tank 11, which is connected into the supply main for the grinders. The tank is filled about one-half with water and one-half with air; the air is compressed by the water pressure, and acts as a cushion on the grinder pressure-water supply-line, tending to maintain a constant pressure. Shower-water supply to the back of the grindstone is shown at 12; this, mixed with the pulp in grindstone pit 13, overflows into the stock sewer 14 beneath the grinders. In the stock sewer, sluicing or thinning water is added through pipe 15. The mixture of fiber then passes through slab rack or strainer 16 and into sliver screen 17, where the coarsest materials are scraped into sliver sewer 18, for disposal, and the fine materials pass through the screen and into the screened stock pit 36, from which they are pumped to the fine-screen distributing box 20 by means of centrifugal pump 19. The stock then passes into fine screen 21

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for further separation of the coarser fibers. Those fibers which do not pass through these screen plates are disposed of as tailings at 22, usually to a refiner. The mixture of fiber suspended in water, which passes through the screen plates, is suitable for manufacture into paper, and it flows into distributing box 23. This stock is then concentrated for storage or for commercial shipment in a thickener or wet machine shown at 24. The thickened stock passes out of the system at 25, carrying a small proportion of water with it.

The water separated from the fibers contains from 15% to 20% of the original fiber content, and passes into a storage tank 27, through pipe connection 26. This tank, commonly called the white-water tank, is the source of supply for grinder showers 12 and for slush water pipe 15. It is very important that the supply of both shower and slush water be continuous while the grinders are in operation; to insure this an auxiliary fresh-water valve is usually provided at 28. The level of the water in the white-water tank 27 controls this valve, and it is so adjusted that it is closed whenever the tank is full of white water. The source of supply for the fresh water may be traced back to the strained-water pit beneath wire 8. The low-pressure fresh water is pumped by centrifugal pump 29 to valve 28, to auxiliary connection 30, located in shower-water supply line, to supply water for floating pulpwood at 31, and to cooling water and hose connections on grinder bearings through reducing valve 32. It will be noted that at 30, provision has been made to use fresh water on grinder showers; this is usually done during the warm weather, to reduce temperatures in the system. Under these conditions, there is a surplus of water circulating in the system, and provision is usually made for reclaiming some of the stock, which would otherwise be wasted in the white water discharged from the system. The save-all 33 is used for straining the fiber out of this white water before passing to waste, as clarified white water, through outlet 34. The reclaimed stock, which is discharged at 35, is mixed with the fiber strained out at 25.

87. Grinder Room and Wheel Pit.—Fig. 41 shows a cross section of a grinder room and wheel pit in a typical mechanical-pulp mill. The numbers up to 36 have the same significance as for Fig. 40. In addition to these common items, Fig. 41 shows: *A*, a horizontal, double-runner, low head, reaction hydraulic turbine, which supplies the power for driving the grindstones

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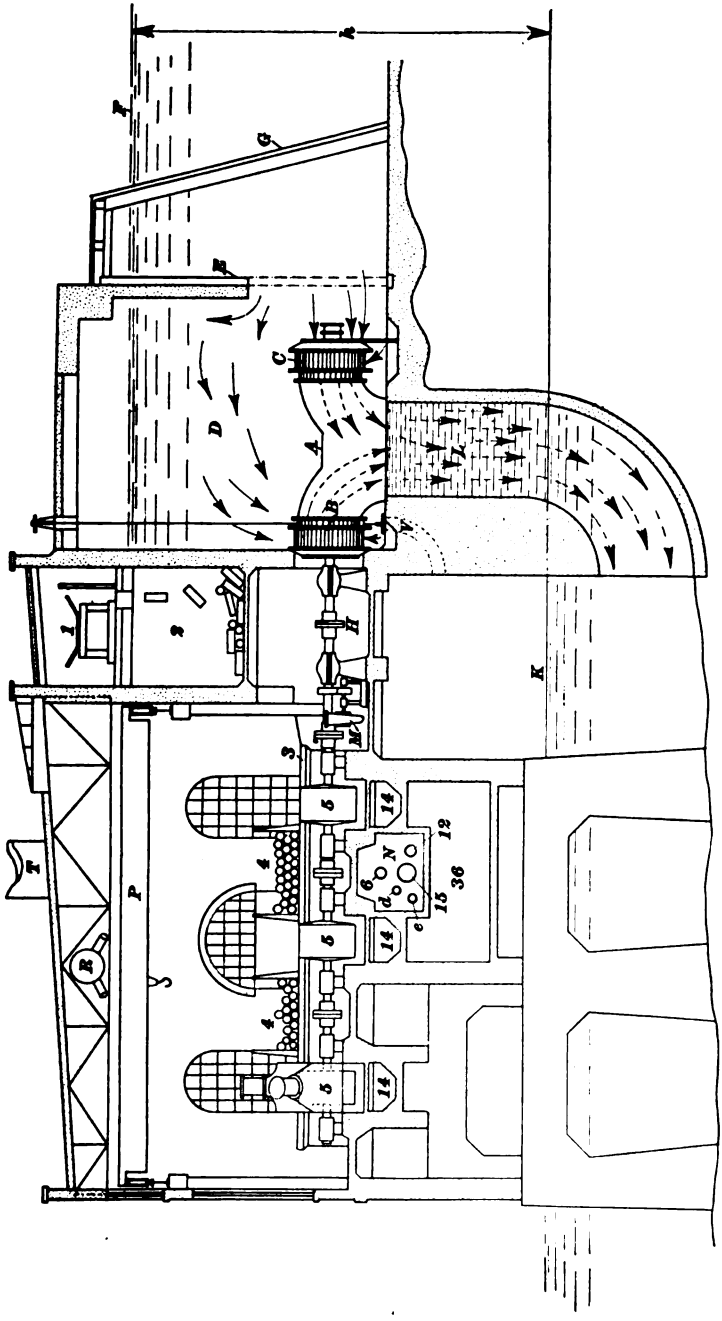

Fig. 41.

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connected to the turbine shaft at *H*. *B*, *C* are guide vanes; the water from wheel pit *D* passes through the guide vanes *B* and *C*, which direct the water against the turbine runners, located just inside the points marked *B* and *C*. The passing of the water through runners causes them to rotate and deliver power to the grinder shaft at *H*. The circulation of water currents in the wheel pit is shown by solid arrows. *D* is the wheel pit, which, during operation of the turbine, is filled with water. *E* is a gate for the wheel pit; during operation this is open, but if the wheel pit is to be emptied, the gate is closed and water is drained out at *V*. *F* is the water level above the dam (forebay). *G* indicates iron racks, which are used to strain logs or other materials out of the water before it is allowed to pass through the turbines. *H* is a coupling, connecting the hydraulic turbine with the grinder shaft; *K* is the tailrace; and L is a draft tube. The water, after passing through turbine *A*, falls to the tailrace water level, through a cylindrical tube, the bottom of which is flared out and enlarged in area. The discharge of water to the tailrace from the turbine is shown by dotted arrows. *M* is a centrifugal pump, belt-connected to the grinder shaft. This is one of the types of pressure-water supply systems for the grinder hydraulic cylinders. *N* is a pipe gallery beneath grinder-room floor; it contains: (*a*) slush-water pipe (white water), 15; (*b*) shower-water pipe(white water or fresh water), 12; (*c*) grinder-pressure water pipe, 6; (*d*) return-water pipe *d* from grinder cylinders; (*e*) fresh-water pipe *e* for cooling bearings, etc. *P* is a crane, for handling grindstones; *R* is an air pipe, for heating and ventilating; and *T* is an exhaust head, for allowing escape of moisture-laden air.

Note.—The two grindstones nearest the turbine are shown with tops (casing) removed.

If the grinders were driven by electric motors, instead of being direct-connected to water turbines, the turbine *A* would have a generator at *H*, and the grinder shaft, in a pulp-mill at a distance from the power plant, would be connected to a motor.

MECHANICAL-PULP MILL OPERATION

88. Establishing Grinder Conditions.—The details of the controlling factors to be taken into consideration for the manufacture of any particular quality of pulp are discussed in Arts. **60–85,** and they will not be repeated here.

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A natural condition that affects grinding operations is the variation in head that operates the hydraulic-power units and the available water storage. Fig. 42 shows sample curves for a typical pulp-mill turbine, operated at a constant speed of 240 r.p.m.

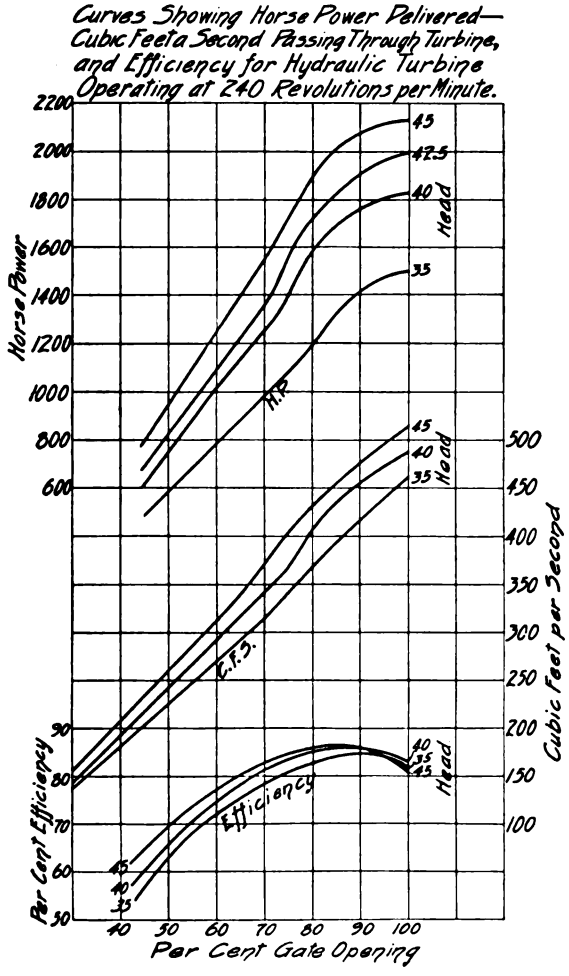

Fig. 42.

In case it is necessary to conserve water, the turbines will be operated at their most efficient gate opening. By consulting the curves, it will be seen that the gate opening giving the maximum efficiency at a head of 42.5 feet is 85%, when the power

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delivered is 1800 h.p. This gives the maximum power for a unit volume of water used under the standard speed of operation for the particular turbine installation tested. The quantity and quality of pulp made will be proportional to the total horsepower available and the degree of sharpness of the stone. In the springtime, when there is a surplus of water, the turbines would be operated at the gate opening which would give the maximum horsepower output. Maintaining a constant speed of 240 r.p.m. at an operative head of 42.5 feet, the curves show that 100% gate opening gives 2000 h.p. output, at an efficiency of 83%.

It will be noted that the speed adopted for turbine operation was 240 r.p.m. This gives on a new 54-inch diameter grindstone, a peripheral speed within the limits of good practice. (See Art. **80.**) With the particular turbine used for driving the grinders, this speed is necessary; but in any case under investigation, the curves shown in Fig. 38, for the relation of speed of operation, production factors, and quality of pulp, as shown by the Mullen (bursting strength) test on the paper, will give some indication as to what results may be expected.

89. Number of Grinders for Turbine Installation.—In order to decide how many grinders may be driven by a turbine installation, or to get an idea of the result of a proposed adjustment of speed and pressure, it is necessary to consider certain known factors and some that are known approximately, but which are subject to variations that are peculiar to the plant management, equipment, wood used, operating methods, etc.

Suppose it is decided to make a news grade of pulp by means of three-pocket hand-fed grinders. The formula of Art. **77** gives

$$\text{h.p.} = 0.000007933 dN(\mu W)G\eta$$

in which, h.p. = horsepower delivered at turbine shaft at the speed and gate opening selected (taken in this example as 1800 h.p.).

d = diameter of grindstone in inches (here taken as 52 in.).

N = revolutions per minute of grindstone (here taken as 240 r.p.m.).

μ = coefficient of friction between the wood and the stones. From tests recorded in U. S. Dept. of Agriculture, Forest Service Bulletin No. 127, this was calculated to be 0.266 at 8.2 lb. per sq.

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in. of pocket area. The variation is practically a straight-line curve, and in this example, 0.23 is used for μ.

W = total thrust of wood against grindstone for one grinder. With a 3-pocket grinder, having pockets 15 in. wide, the grinding surface per grinder, when pockets are 24 in. long, is $15 \times 24 \times 3 = 1080$ sq. in. If the pressure per square inch of pocket area is 25 lb., the total thrust is $W = 1080 \times 25 = 27{,}000$ lb.

G = number of grindstones connected to the source of power; its value is to be found.

η = efficiency of power conversion = fraction of total power supplied that does useful work by the grinder. This quantity will vary with the number of grindstones connected to the same source of power, their alinement, the amount of pocket binding, character of wood, etc. For a certain electrically driven grinder installation, this was found to be 0.70, and this value will be used here for η.

Solving the above formula for G, and substituting the values here given,

$$G = \frac{1800}{0.000007933 \times 52 \times 240 \times .23 \times 27000 \times .7} = 4.2 \text{ grinders.}$$

Evidently, four 3-pocket grinders (*i.e.*, 4 grindstones) will be sufficient for this installation.

In the above equation, the total pressure against the grindstone is 27,000 lb.; hence, each hydraulic cylinder must supply a pressure (th ust) of $27000 \div 3 = 9000$ lb. If the grinder cylinders are 14 in. in diameter, the necessary water pressure for their supply is calculated thus:

Let T = total of one cylinder (= 9000 lb.);

d = effective diameter in inches of hydraulic cylinder, or 14 in. in this case;

p = specific pressure of water supplied to hydraulic cylinder in pounds per square inch;

then, $.7854 \times 14^2 \times p = 9000$, or $p = \frac{9000}{.7854 \times 14^2} = 58.5$ lb. per sq. in. It would be well to have the water pressure about 60 lb. per sq. in.

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90. It will be noted that the coefficient of friction between the revolving stone and the pulpwood stick was taken as 0.15. This factor is subject to considerable variation, depending on the degree of sharpness of the stone, the grit of the stone, the amount of water used on the grinder shower, and the actual physical condition of the wood. When establishing grinding conditions in any particular mill, minor adjustments in pressure will be found necessary to provide for variations continually met with during operation.

91. Starting Up the Pulp Mill.—It will be assumed that all pumps and equipment are at rest, and that all tanks and pits are in the usual condition when the pulp mill is started up. Since the mechanical-pulp making process is a continuous one, a regular sequence of operations is necessary to starting up the mill.

The following outline is given, using Fig. 40 as a reference.

1. Open valve in pipe through dam 7, supplying fresh water to pump-well 8.

2. Start pumps 9 and 29; at the same time, supply more air to tank 11, if necessary.

3. Valve 28 will then fill up tank 27, which will furnish supply of water at control valves at 12, 15, 16, 18.

4. Open valve 15, to fill up the stock sewers 14 and screen pits 36 with water.

5. Replace all dam boards for grinder pits at 13, and open shower pipes 12 on back of stone, so that grinder pit will fill up with water and flow over into stock sewer 14.

6. Start in operation screens 21, and deckers or wet machines 24.

7. Start screen 17, and open showers at 16 and 18.

8. Slowly open gates to hydraulic turbines to about $\frac{6}{10}$ of the usual operating setting, making sure first that all the pressure feet on the grinders are delivering pressure against the stones.

9. Release pressure from some of the pockets, so that turbine starts revolving grinders; then put pressure on just enough pockets to keep stones in rotation while the turbine gates are opened to operating position. Supply a large amount of water on the stones, so they will not become heated. At the same time, the grindstone pits should be kept full of water.

10. Start stock pump 19 and regulate its discharge valve so that the volume pumped is just sufficient to carry away the

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mixture of fibers and water that passes through the sliver screen beneath 17.

11. Adjust flow through valve 15 until stock is of desired consistency for screening and pumping.

12. The system is now in continuous operation. The water used for conveying and classifying the fibers enters the stock sewers 14 and is pumped through the system to deckers 24, where the fibers are strained out, and the white water passes through pipe 26, white-water tank 27, and finally back to grinders.

92. Operating a Hand-fed Grinder.—One man usually operates two hand-fed grinders. When there are more than two

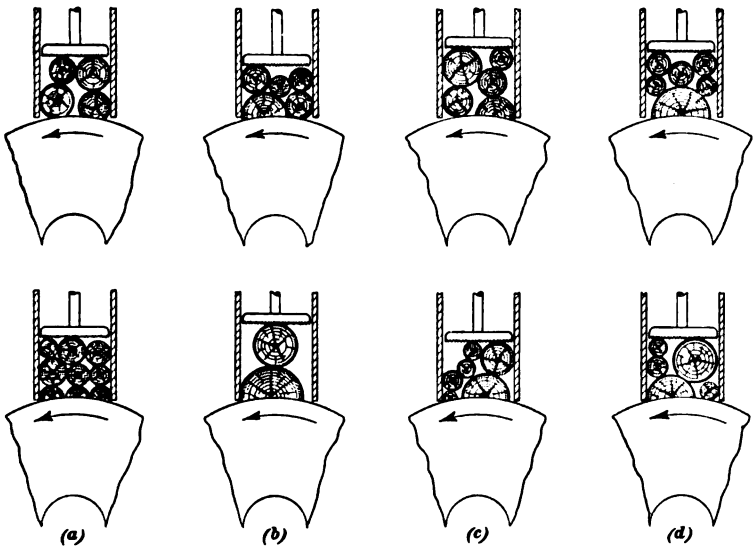

FIG. 43.

grinders connected to one source of power, the grinder operators must so arrange their pocket charging that there will be a minimum number of pockets off at the same time. The wood is piled by a helper in racks convenient to the reach of the operator.

A general outline of the duties of a grinder operator is as follows:

1. He must sort out his wood and place it in the grinder pockets in such a way that there will be no pocket binding. Pocket binding causes a reduction in the pressure of the wood against the stone, due to some of it being transferred to sides of pockets by arch action. In Fig. 43, (*a*) and (*b*) show a good

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arrangement of wood in a pocket, (*c*) and (*d*) show a poor arrangement of wood in a pocket.

2. He must watch the motion of the tell-tale connected to each pressure foot, so he may be sure that there is no pocket binding or other source of interference with grinding. With inexperienced operators, the speed of the grindstones may become excessive, due to binding of wood in pockets.

3. He must regulate the temperature at which grinding takes place, by adjustment of the valve controlling the shower water on the back of the stone. As a guide to whether this is properly adjusted, he must watch the appearance of the pulp being discharged from the grinder pit.

4. He must keep an even flow of stock over the dam boards on the front of the pit. When this does not occur, it is necessary to clean out the grindstone pit with a fork-like tool provided for this purpose.

5. He must keep an accurate record of the number of racks of wood ground, unless the recording is otherwise provided.

93. Stone Dressing.—The stone dressing operation is the most important job in the mechanical-pulp mill. This operation is carried out by a man specially trained for this work, usually called a *jiggerman*, who follows the instructions of the grinder-room foreman.

The object of the routine stone-dressing process is to maintain the stone production, taking into consideration the quality of wood ground, the grit, hardness or softness of the stone to be dressed, and the paper-making quality requirements of the stock to be made. To carry out this work satisfactorily, the foreman must closely watch the variation in quality of wood, the freeness and general character of the final fiber mixture, the degree of sharpness of all the stones in the pulp mill, and the temperature at which the grinding is being done. It is here assumed that the other controlable variables remain practically constant.

By inspection, the foreman notes the amount of stock overflowing from the grindstone pit and checks the rate of production by feeling the rate of advance of the pressure foot as indicated by the telltale attached to the pressure foot of the grinder pocket. If the flow over the dam boards is small and the rate of cutting low, it is an indication that the stone needs sharpening or that some of the pockets are binding. If an examination shows the pockets are all free from binding, the fiber made is uneven, or too

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fine and short, and the stone is warmer than the others, it is safe to say that the stone requires sharpening. The decision to sharpen a particular stone is determined largely by comparison with the productive rates of the other stones and the freeness required in the finished stock.

The grinder-room foreman may find, by an examination of stones, that the pulp is discharged from a grindstone pit in thick, bristly cakes. This is an indication that the stock is coarse and free.

In many cases, the stock may have the correct consistency in passing out of the grinder pit and may appear to be satisfactory, but the rate of production may be found to be high, by examination of the movement of the telltale. An examination of the stock in the blue glass test will show whether the uniformity, fiber coarseness, and length are satisfactory for the quality of pulp desired to be made. If the stock is found to be too coarse, or what amounts to a too free stock, the grinder-room foreman will "knock back" or dull the stone. In any given case, this process will be carried out in accord with the burring methods in use for the particular pulp made. The object is to dull the surface of the stone by the use of a finer-cut burr or brick, which is passed over the surface at a pressure decided upon by the grinder-room foreman, as proper to meet the particular conditions.

95. There may be large, fast grown wood in the grinder room during part of the day and small, slow grown wood in the grinders during the rest of the time. On the other hand, there may be a mixture of both woods in the grinder room at the same time. Whenever possible, it is desirable that two woods of such totally different qualities be ground on separately prepared stones; but if this is not practicable, the grinder-room foreman must adjust his stone surfaces in such a way that the quality of the final stock mixture is up to specifications, basing his action on all the information available.

In some cases, as in the spring of the year, it may not be possible to meet the requirements of stock quality with the combination of natural conditions and a particular type of burr. The type of burr used must then be changed. When changing the burr on a grindstone surface, it is the usual practice to first "roll" the impression of the old burr from the face of the stone, using a fine cut burr, such as a 10-cut diamond. The fine burr is passed over the old surface a number of times, depending on the hardness

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of the stone; finally, the new burr impression placed on the stone's surface, in the same manner as is generally used in stone sharpening.

96. The nature of the machines on which most mechanical pulp is used is such that the more uniform the quality of the stock supplied them the more efficiently they may be operated. It is therefore apparent that the grinder-room foreman must so arrange his stone sharpening that the interval between sharpenings is as constant as possible. Should a large number of stones be sharpened at one time, the physical properties of the stock would change (see Fig. 44) and cause operating trouble on the paper machines.

After sharpening a grindstone, the fiber mixture is usually made up of a combination of fine, re-ground fibers and of short, coarse fibers; the mixture gives a free stock and, consequently, a poor felting one. As the sharp irregular points on the stone's surface are worn off, the fibers are drawn out and the stock slows up. These variations must be thoroughly understood, closely watched, and well managed by the grinder-room foreman. This is where the art in the manufacture of mechanical pulp comes strongly into play.

97. Importance of Freeness.—Reference has been made several times in Arts. **88–96** to the importance of the freeness of a mixture of mechanical-pulp fibers, and its indication of how the stock will act on a paper machine. Fig. 44 is a reproduction of a daily freeness-control chart used in a hand-fed mechanical-pulp mill, making a news grade of pulp. At the time the chart was compiled, a mixture of black and white spruce containing less than 5% of balsam fir was being ground, 68 horsepower to the ton was being used, and there were 81 feet of stone width in operation, grinding 0.95 cord per foot per 24 hours. The intensity of pressure per square inch of pocket area averaged 27 lb., the average operating speed was 234 r.p.m., the grinding temperature was approximately 150°F., and the stones were dressed with a No. 10, 3½-inch lead, spiral burr.

Curve 1 shows the corrected variation in freeness of the stock leaving the sliver screens at 30-minute intervals for a period of 24 hours. This is the guide used by the grinder-room foreman in dressing the surfaces of his stones. The desired uniform freeness on the Green tester was 95.

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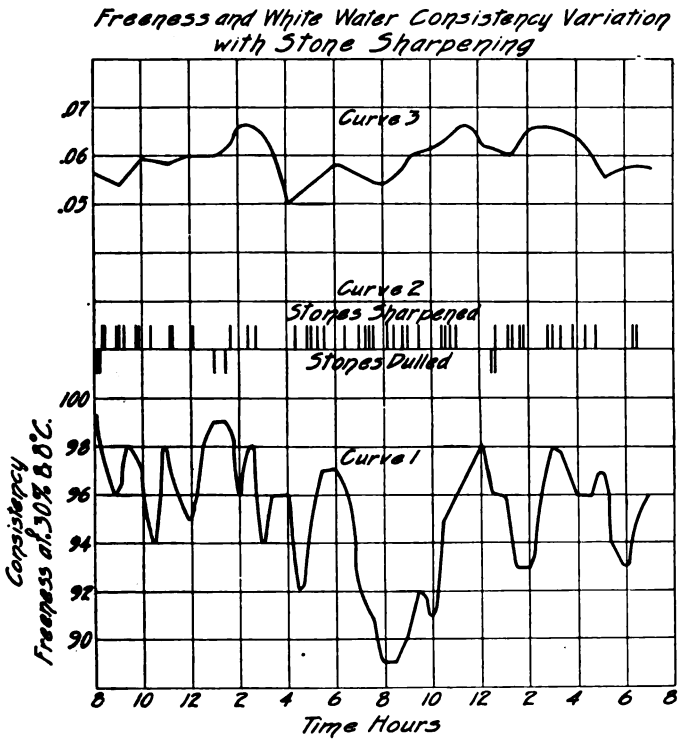
Curve 2 shows the variation in number of stones sharpened and dulled, and the time thus occupied. The stones sharpened are indicated by single vertical lines, placed above the base line at the point on the time scale where the stone was sharpened. Whenever a stone was dulled, it is indicated by a similar vertical line



Curve 1. Time Variation in Freeness with Stock Leaving Sliver Screens.
Curve 2. Variation in Stones Sharpened and Dulled with Time.
Curve 3. Variation in Consistency of Slush White Water with Time.

FIG. 44.

below the base line. A close study of the relation of the time of burring to the freeness of the stock will show the regulation of the burring and dulling by the grinder-room foreman, in an attempt to maintain a uniform freeness of stock. In Art. **16** the determination and expression of uniformity of groundwood pulp fibers were referred to. Information of this kind to supplement the

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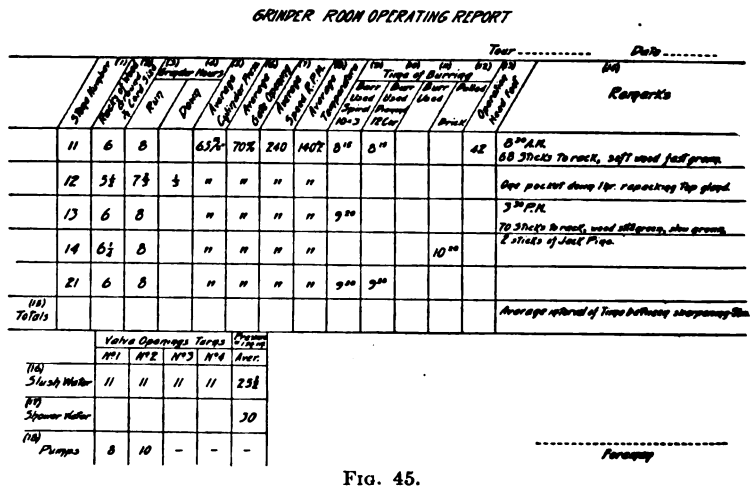
freeness test would enable the grinder-room foreman to decide how far to go with his dulling and sharpening operations, in an attempt to maintain constant a factor, such as freeness, which does not completely determine the operating qualities of a stock.

Curve 3 shows the variation in consistency of the white-water used for thinning the stock discharged from the grinder pits. Since the fiber contained in this white water when mixed with the fresh ground pulp changes the drainage characteristics of the stock, a knowledge of this variation is necessary in the interpretation of the freeness of the finished stock.

98. Operating Control and Records.—The manufacturer of mechanical pulp endeavors to get the maximum amount of pulp


GRINDER ROOM OPERATING REPORT

Tour ---------- Date --------

	Stone Number	Pockets Open	Pockets Partly Loaded	Run	Down	Average Cylinder Press.	Average Gate Opening	Average Speed R.P.M.	Average Temperature	Type of Burring: Burr Used (Speed / Power)	Burr Used (Power)	Burr Used	Pulled / Brick	Grooves Need Turn	Remarks
	11	6	8		63¾	70%	240	1402	8¹⁵	8¹⁵			42	8³⁰ A.M. 68 Sticks To rock, soft wood fast grove.
	12	5½	7½	½	"	"	"	"						One pocket down 1/2 hr. repacking Top glazed.
	13	6	8		"	"	"	"	9³⁰					3³⁰ P.M. 70 Sticks To rock, wood still green, slow grind.
	14	6½	8		"	"	"	"				10³⁰		2 sticks of Jack Pine.
	21	6	8		"	"	"	"	9³⁰	9³⁰				
(18) Totals														Average interval of Trips between sharpening 8hr.

	Valve Openings Targs				Pressure Targs
	N°1	N°2	N°3	N°4	Aver.
(16) Slush Water	11	11	11	11	25½
(17) Shower Water					30
(18) Pumps	8	10	-	-	-

Foreman

FIG. 45.

of suitable quality for paper manufacture from the minimum amount of wood and power, and with the least expenditure of effort and materials. In order intelligently to carry out this work, accurate quantitative information must be compiled of the operating conditions from hour to hour and from day to day. This data must then be arranged in the form of records and charts, to furnish a guide for future operations.

Fig. 45 gives a sample report for a mechanical-pulp mill. It is usually made out by the grinder-room foreman for his period on duty. It shows the details of his operations, and is used as a

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guide for his operations and for the compilation of production statistics.

Column (1). This space is marked *stone number*. It gives a record of the actual number of grindstones run. Here 11 refers to No. 1 line, No. 1 stone and 21 refers to No. 2 line, No. 1 stone (there are 3 stones on each line.)

Column (2). Under this space, the grinder-room foreman enters the number of racks (here ½ cords) of wood ground by each stone; or, in the case of a grinderman operating two stones, the amount of wood ground by the two stones combined. This figure must be reported accurately, since it is the basis for the calculation of the efficiency of conversion, as will be described later.

Column (3). In this space, the number of grinder hours run are entered; opposite 11, in column 3, the 8 indicates that the grinder has been operated continuously for the full 8 hours of the tour or shift.

Column (4). In column 4, the loss in grinder-hours is indicated; opposite line 12, it is indicated that one-third of a grinder-hour was lost; and in column 14, the cause of this is reported to be due to the re-packing of a cylinder gland.

Column (5). This indicates the average pressure carried on the hydraulic cylinder. For any given grinder, this average should remain fairly constant, so long as the same quality of pulp is being made.

Column (6). This refers to the amount that the gates on the hydraulic turbine are open. Knowing the operating head on the turbine and the speed of rotation of the grindstones, by referring to the turbine characteristics curves, Fig. 42, the horsepower delivered to the grinders may be calculated.

Column (7). This gives the average revolutions per minute for the grinder. When the revolutions per minute of the grindstone and the diameter of the stone are known, the peripheral speed may be calculated.

Column (8). This gives the average temperature of the stock in the grindstone pit, in degrees Fahrenheit.

Columns (9), (10), (11), (12). These columns are used for reporting the particular burr used for dressing the stone's surface and the time that the stone was sharpened.

Column (13). In this column, the operating head of water for the hydraulic turbines is given. It is calculated as the difference in level of the water in tailrace and forebay.

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Column (14). In this column, general remarks relating to the operating conditions, quality and size of wood, etc. are indicated.

Row (15). This row gives the totals of all the averages.

Row (16). In row 16, under Nos, 1, 2, 3, 4, the number of turns of opening for each of the white-water valves supplying slush water to the stock sewers is indicated. These valves should all be calibrated, in order that they may be adjusted to supply the amount of water required for varying number of grinders in operation. The average pressure on the pipe line supplying white water is entered in the last column of row (16).

Row (17). In the last column of row 17, the pressure in the shower-water pipe line is indicated. This acts as a guide for detecting any trouble, such as blocked pipes, and to make certain that a large enough supply is available at the grinder valves.

Row (18). Under Nos. 1, 2, 3, 4, the valve openings of the stock and pressure-water pumps are indicated.

99. Determining Production.—The amount of pulp made during the day is determined in different ways, depending upon the design of the pulp mill. The most accurate method, is to run the stock over wet machines (see Section on *Treatment of Pulp*), and then weigh and test for fiber content the pulp from the wet machines, or after it is pressed in hydraulic presses. When the amount of fiber of commercial quality is determined, the wood consumption is obtained from column (2) in the Grinder Room Operating Report, and the yield, or pounds of bone-dry fiber per barked cord, is calculated.

The efficiency of conversion of wood into mechanical pulp ($= E$) is an important control figure. This is calculated by dividing the bone-dry weight of commercial quality of pulp per 100 cu. ft. of barked wood ground ($= A$) by the bone-dry weight per 100 cu. ft. of barked wood ground ($= B$); that is,

$$E = \frac{A}{B}$$

For example, suppose there are 90 cu. ft. of solid, barked wood to the cord, and, as result of test, it is found that the wood ground contains 28.40% moisture and weighs 25.94 pounds per cu. ft. bone-dry. Suppose further that 100 cords of wood have been ground and 105.80 bone-dry tons of mechanical pulp have been made then

$$\text{wood ground} = 100 \times 90 = 9000 \text{ cu. ft.}$$

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Bone-dry weight of commercial quality of pulp per 100 cu. ft. of barked wood ground is

$$\frac{105.8 \times 2000}{\frac{9000}{100}} = 2351.1 \text{ lb} = A$$

Bone-dry weight per 100 cu. ft. barked wood is

$$100 \times 25.94 = 2594 \text{ lb.} = B$$

Efficiency of conversion is

$$E = \frac{A}{B} = \frac{2351.1}{2594} \times 100 = 90.64\%$$

This loss of about 9% of the wood is accounted for as screenings, or fibers unsuitable for paper making because of their size; white-water losses of very fine fiber, which passes from the circulating system with the surplus in white water passing to waste; water soluble constituents in the wood, which may easily go into solution, due to the finely divided state of the wood fibers. The horsepower per ton of pulp produced in 24 hours is equal to the rate of power delivered by turbines or motors divided by the bone-dry tons of pulp made in 24 hours. If, in the preceding example, an interpolation in the turbine characteristics curves showed that each of the four turbines used for driving the grinders was delivering on the average 1750 h.p., the total horsepower delivered would be $1750 \times 4 = 7000$ h.p.

Then, $$\text{h.p. per ton} = \frac{7000}{105.80} = 65.22 \text{ h.p. per ton.}$$

QUESTIONS

1. Name the principal items of equipment in a mechanical-pulp mill.
2. Explain why either a decreased stream flow or a largely increased stream flow may result in a decrease in available power from hydraulic turbines.
3. What are the duties of a grinder room foreman?
4. What are the duties of a man operating a hand-fed grinder?
5. How is the time and degree of dressing a grindstone determined?

GRINDING PROCESSES

100. Variation in Power for Same Quality and Quantity of Output.—When considering the grinding of mechanical pulp for different grades of paper, the reader is referred to Fig. 34(*b*)

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which shows that with a given horsepower input to the stone, for a given condition of speed and pressure, pulp of a wide variation in quality may be made. This is, of course, accompanied by a variation in tons of pulp made, and is caused by the condition of the surface of the grindstone.

In Arts. **28** and **29,** the importance of the grit of the stone was pointed out. It is easy to understand that the more suitable is the grit in the stone for the quality of pulp to be made the less it is necessary to depend on the design of burr used. Without going into any more detail, the thought which the reader should get is that conditions vary in different pulp mills, depending upon just how the designer has made use of his natural conditions, and upon how the operation is carried out as compared with the original idea, as well as upon the policy of the management and the kind of pulp desired.

An example that illustrates this point was given to the writer by one of the companies manufacturing burrs. In a mill making catalog-grade pulp, it was decided to try the same burr that was being used in another mill, with very good results, on the same grade of pulp. The burr in successful use was a No. 12 spiral, with a 2-inch lead. The same burr in the new mill gave a fine-fibered, slow stock; after some experimental work, it was found that a No. 7 spiral burr with the same lead gave the desired grade of pulp. In the new mill they used 30 lb. per sq. in. pressure on 14-inch cylinders, while in the old mill 60 lb. per sq. in. pressure on 14-inch cylinders was used, indicating twice as much power to the grinder in the old mill. In the old mill, they had the advantage of the high intensity of pressure per square inch of pocket area, which, for a catalog-paper quality of pulp, required a fine spiral burr (No. 12 spiral, 2-inch lead). In the case of the new mill, their power conditions and pocket area, required the use of a lower pressure per square inch of pocket area; but to get the catalog-paper quality of stock, a coarser spiral burr was necessary. Assuming, then, that the stocks made by both mills were the same, it is apparent that the mill using the lower pressure was paying more for power and labor attendance than was required by the other mill, to produce the stock quality required.

101. Newsprint Grade of Pulp.—The machines used for making newsprint paper vary in details of design and operation. If the speed of operation is high and the wire length (see Section on *Paper Machines*, Vol. IV) is short, a freer stock must often be

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made than for a machine operated at the same speed, but with a longer wire. The freeness of the stock made must also be varied with the proportion of sulphite used, the amount of beating and jordaning of the stock, the amount and kind of filler used, the temperature of the stock mixture, and the amount of fiber contained in the re-circulated water used for suspending the stock passing out on the wire. Variations in freeness of the stock, as delivered to the paper machine that is making newsprint, may be compensated for to a certain extent by varying the volume of water used for suspending the fibers; if the stock is made free in the grinder room, more suspending water must be used on the paper machine, to form the sheet on the wire; and if the stock is slow, less suspending water is required.

For newsprint pulp manufacture, especially for machines operated at over 600 feet a minute, it is almost essential to have a good quality of spruce wood. Small quantities of balsam fir, provided it is sound, are sometimes ground with spruce, without material effect on the quality of the pulp made.

A power consumption of from 60 to 70 h.p. per ton will be required for newsprint quality of mechanical pulp. A medium grit stone of medium hardness is best for this grade of pulp.

For making high-speed news pulp, a No. 8 to No. 10 spiral burr, with a lead varying from 1½ inches to 3 inches is in quite general use. The stone is sharpened with this burr, and then a No. 12 to No. 14 diamond point burr is passed lightly over the stone's surface. The object of the use of the diamond burr over the spiral burr is to slow up the stock and smooth off the rough edges, which would tend to make a high waste. The freeness of the pulp made may be controlled by heavy or light use of the diamond burr.

Some mills use a No. 6 to No. 10 cut diamond for dressing the stones, but as explained in Art. **74**, the fiber made is more chunky, and it does not usually have the strength which the spiral burr gives.

Some of the mills using the older newsprint machines, which operate at slow speeds (under 600 ft. per min.), dress the stone's surface with a No. 8 to No. 10 cut thread burr. The reader has already learned the characteristics of the pulp made on a stone sharpened with a thread burr. Where the white-water system is in continuous circulation, losses of fine fiber in white water from

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the system are prevented; the sheet of paper made by this method usually has a good formation and finishes well.

Pressures of from 25 to 30 lb. per sq. in. of pocket area are in quite general use for news pulp manufacture. The peripheral speed of the stone for news pulp varies between 2500 and 3500 feet per minute. Hot grinding is also in general use for news grade of pulp on this continent, the temperature varying from 130° to 160°F. Hot grinding has the tendency to make long-fibered stock and to cut down the white-water loss that occurs with cold grinding.

102. Wall-Paper Grade of Pulp.—The quality of pulp required for wall-paper stock varies much more than for newsprint. This is due to the many different weights and textures of paper made. For this reason, the quality of wood is not so important, and larger quantities of the other types of coniferous woods may be mixed with spruce for this class of pulp.

Wall-paper stock is usually freer and coarser than news stock and requires from 55 to 65 h.p. per ton of production. The stone for most grades of wall-paper stock is a little coarser than that used for newsprint, and is of medium hardness. A No. 6 diamond, a No. 4 to 6 straight cut, or a sectional burr,[1] will give the desired quality of pulp.

The pressures used in mills making this grade are between 25 and 35 lb. per sq. in. of pocket area, being governed by the power to the grinder. The speeds used are almost the same as those used for news grade of pulp. Hot grinding is also used, the temperature being within the same limits as for news pulp.

103. Wall-Board Grade of Pulp.—For wall board, a very free, coarse stock is wanted. The power consumption varies from 50 to 60 h.p. per ton of pulp made. The stones are dressed with No. 4 diamond, straight cut, or sectional burrs. The main idea in stone dressing is to keep the stones open and cutting freely without regard to waste. This is because the product is not finely screened, and practically all the pulp is included in the sheet of wall board. High pressures per square inch of pocket area are used, depending on the power available per stone.

[1] A sectional burr is made up of 5 or 6 special cast-iron disks about ¼ in. thick, with teeth on the periphery of each. They are graded according to the number of teeth per inch of periphery; thus, a burr with 6 teeth per inch is called a 6-cut, or No. 6, burr. A sectional burr leaves an impression on the stone's surface similar to the straight cut burr, but instead of being in a straight line the impression is wave-shaped.

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104. Container-Board Grade of Pulp.—Container-board pulp is made in two grades: first, the fiber for the box structure; second, the fiber for the box liner.

The fiber for the box structure is very free pulp, ground similar to that for wall board, from 50 to 60 h.p. per ton being used. The screens used for this fiber are somewhat finer than for wall board. The liner fiber is fine and well screened; the grinding taking from 75 to 80 h.p. per ton.

105. Cheap Book-Paper Grade of Pulp.—Pulp for cheap, book paper is a slow, well-screened stock, free from small slivers. This quality of stock must form well into a sheet and take a good finish; a minimum of about 80 h.p. per ton is used for this grade of pulp. A fine grit, medium-hardness stone, dressed with a fine burr, such as a 12-cut spiral, with a 2-inch lead, is used for dressing the stone's surface.

106. Manila-Paper Grade of Pulp.—Groundwood for manila paper must be strong and long fibered and must be free from slivers, which will show plainly in a highly calendered sheet. Spruce wood is preferable for this class of pulp, and the stone grit should be of rather fine texture. To get a long-fibered pulp, a spiral burr with a lead of from 1 to $1\frac{1}{4}$ inches is best, the pitch of the burr used being determined largely by the pressure of the wood against the stone and the horsepower available per grinder. The power consumption per ton of pulp is from 75 to 80 h.p.

107. Brown Pulp.—Before grinding wood it is sometimes steamed or boiled under various conditions of temperature and pressure. This preliminary treatment is carried out in order to get a stronger pulp for use in papers where strength is of greatest importance. The action of the cooking process on the non-cellulose constituents of the woods gives the pulp made from the cooked wood a brown color and the product is commonly called **brown pulp.**

The manufacture of this grade of pulp has the following additional cost items above the unsteamed-wood grinding process.

(1) Additional cost for cooking equipment.

(2) Additional cost for wood handling to and from this department.

(3) Additional cost for steaming operations.

(4) Additional cost for wood due to loss in yield over the unsteamed grinding process due to solution of some substances.

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The controlling factors may be varied when grinding steamed wood in a similar way to those used for unsteamed wood. If the surface of the stone is sharp and coarse, the pulp made will be suitable for wrapping paper manufacture; if the surface is fine and of medium hardness a pulp may be made which, after screening and mixing with small amounts of chemical pulp, can be made up into an imitation kraft paper.

In the experiments reported in the U. S. Forests Products Bulletin No. 343 on the grinding of cooked and uncooked spruce, the following conclusions were arrived at, based on these tests:

1. Cooking spruce prior to grinding results in a stronger fibered pulp, although at least 25 per cent more power per ton is required than is used in grinding untreated wood. The horsepower consumption per ton when grinding under conditions of varying cylinder pressure decreases to a minimum at approximately 65 pounds pressure on a 14-inch cylinder; this holds for dull or sharp stones.

2. When wood is cooked under conditions of constant pressure and varying lengths of time, the maximum power consumption per ton of pulp is obtained after cooking for six hours. This holds true regardless of the pressure at which the cooking takes place, between 0 and 75 pounds gauge pressure.

3. Wood which is cooked at high pressure requires more power per ton of pulp when ground under the same conditions of cylinder pressure, speed, and surface of stone than wood which is cooked at lower pressure, if the duration of the cook is the same. Likewise, the production of pulp in 24 hours is materially less when the wood ground has been cooked at high pressure than if it had been cooked at low pressure.

4. The yield per cord is influenced very greatly by the length of time the cooking is carried on and the pressure of the cook, being much lower for high pressures than for low and also for long cooking periods than for short.

5. The power to the grinder increases with speed and pressure of grinding and decreases with the degree of sharpness of stone. There is also a very slight increase in the power required with increase of temperature, other conditions remaining constant, while the thickness of stock in the grinder pit has almost no influence. Under like conditions of all other factors, the power to the grinder is less for steamed wood than for green or seasoned wood untreated.

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6. With a fixed amount of power to the grinder and a fixed grinding pressure, the speed of the pulp stone will vary greatly, depending on the length of time the wood has been steamed and the steaming pressure. Unsteamed wood will grind at low speed, while that steamed a long time will grind at high speed, with the same amount of power to the grinder.

7. There is little if any difference in the quality of pulp obtained as a result of using either the boiling or steaming process. The color, length of fiber, and yield are practically the same, if the boiling or steaming is carried on at the same temperature.

8. The amount of pulp produced in grinding cooked wood with a fixed amount of power to the grinder is less at high pressure and low speed than it is at low pressure and high speed. This results in a greater horsepower consumption per ton of pulp at high pressure and low speed.

108. Special Processes.—In the **Enge process** for the manufacture of mechanical pulp, the blocks of wood are immersed in boiling water in a closed boiler. The temperature of the boiler is raised to 266° F., and the pressure to 176 lbs. per sq. in. The wood is cooked under these conditions for three hours; after which, it is removed from the boiler and ground, with the axis of the pulpwood stick inclined 10° to a line drawn at right angles to the axis, and tangent to the face, of the stone. The grinding action, therefore, is lengthwise of the pulpwood stick which results in a longer fiber length to the pulp made.

In the **Friedsam process,** which is used particularly for loaded papers, the loading material is suspended in the shower water. This allows the loading to penetrate the fibers; and it is claimed that the grinding process is accelerated, horsepower required per ton of pulp is reduced, that less trouble results from wood resin, and the final color of the sheet of paper is improved. In carrying out this process the loading material used must be in a very finely divided state, so that it may be carried by the shower water to the grindstone.

GRINDER PRESSURE SYSTEMS

109. Requirements of a System.—Water under pressure is in almost universal use for supplying the thrust for the blocks of wood against the grindstone. This is due to its accessibility

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around pulp mills and to its physical property of being practically incompressible.

Grinders have been made with a mechanical feed of the wood against the stone. With this equipment, the rate of grinding was controlled by the rate of feed of the mechanism for the pressure foot. The variation in intensity of pocket pressure was not so great as with the hydraulic feed; but the load variation on the driving apparatus was large, and the machine was complicated and costly. A new development of this type has recently been patented in the form of a magazine grinder, in which there is a single, vertical wood chamber. Chains with lugs draw down at either side, and the arch action of the sticks pulls the wood against the stone.

110. The water supplied to any grinder-pressure system should be filtered, to remove any grit or foreign matter that would cause wear or blocking up of the system. The water should also have a slight natural alkalinity, so that the equipment will not be corroded. The design of the pressure system should be one that is dependable in operation; and it should be subject to adjustment, to meet variation in natural conditions. The importance of dependability in operation can be appreciated, when the effect of removing the load from a hydraulic turbine at full gate opening is considered. It is the usual practice to have some secondary source of pressure-water supply for pressure systems, to prevent the bursting of grindstones by excessive speeds, should the pressure in hydraulic cylinders fail. This is usually supplied by connecting into the fire-protection system or other adequate water supply.

Some pulp mills use two sources of pressure water: a high-pressure system, which is used for grinding purposes only; and a low-pressure system, which is used for returning the hydraulic pistons to the starting end of the stroke. This arrangement involves more piping and, consequently, costs more. It reduces the pressure fluctuation on the pressure-supply line to the grinders, and it allows the use of smaller capacity high-pressure pumping equipment.

111. Fig. 46 gives a diagrammatic layout of a natural-head, hydraulic-pressure system. This system may be used when the elevation of the water in the forebay is sufficient to supply the desired pressure in the hydraulic cylinders of the grinder. Referring to Fig. 46, *A* represents water level in the forebay; *B* is the

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dam, and *C* is the valve controlling the supply of water to the filter *D*. Valve *F* is a shut-off valve for the pressure-supply main, and *E* is the pipe line supplying water to the grinders. The pressure available in the hydraulic cylinders is governed by the difference in level marked *G*. This system is the simplest of all systems; but the grinders are subject to speed variation during the pocket charging, if hydraulic driven, due to the constant pressure in the grinder cylinders and to the variable load on hydraulic turbines.

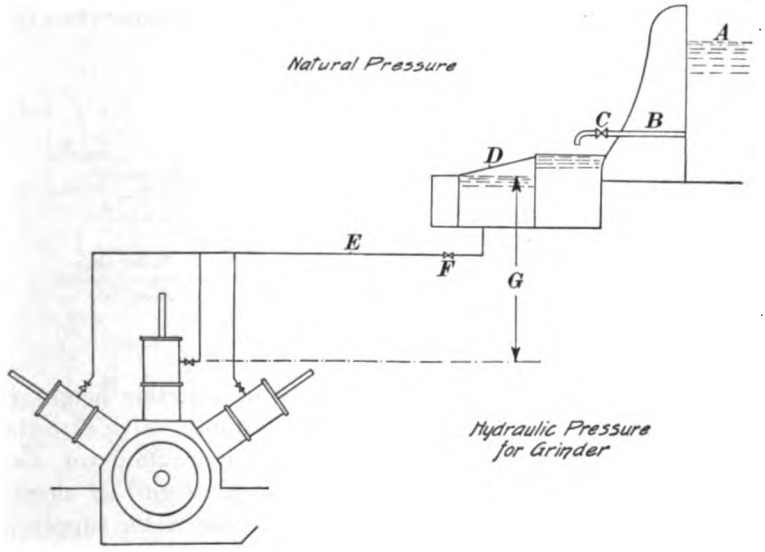

FIG. 46.

A reducing valve may be placed adjacent to valve *F*, if the pressure due to the head is too high. When the reducing valve is set, constant-pressure water is supplied to the grinders.

112. Hydraulic-Accumulator System.—This system, shown in Fig. 47, involves considerable equipment, and is therefore expensive to maintain; it is quite commonly found in the old types of pulp mills.

Filtered water is supplied from clear well *D*, and is drawn into the triplex hydraulic pump *G* through a control valve *F* and suction line *E*. The pump delivers water to the bottom of the hydraulic-accumulator cylinder *L* by means of pipe *H* and through valve *J*. The pressure on the discharge side of pump *G* is governed by the weight *M* supported by the hydraulic-accumula-

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tor ram or piston N. The pressure in supply line O to grinders P may be varied by putting on (or taking off) weights on top of M. The object of the hydraulic accumulator is to accommodate variable volume requirements on the grinders and still maintain a constant pressure. The pump G is run at constant speed, and as water is drawn away at O, the platform M falls until it strikes the trip I. This opens valve F, by means of a system of levers, which allows pump G to deliver water into the system. The surplus above the requirements used for grinders raises the plunger N. The pump should have a capacity greater than the normal demands of the system.

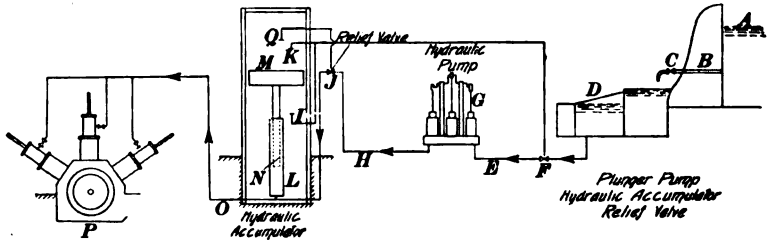

FIG. 47.

When the platform M has been raised to a certain height, it strikes trip lever K. This shuts off the supply valve F to the hydraulic pump, no water is delivered to the accumulator, and the ram N, with its superimposed weight (platform) M slowly descends until trip I is again moved, when the water supply is opened to the pump through valve F. If the valve trip K failed to stop delivery of water to cylinder L when the demand for water at the grinders was small, the weighted platform M would next strike safety trip Q, which would allow the water delivered by the pump to be wasted through relief valve J and would also prevent further rise of the plunger N.

113. Centrifugal Pump Belted to Grinder Shaft.—Fig. 48 shows a general layout of this system. Filtered water is supplied to centrifugal pump K through A-B-C-D-F-E, as in the previous cases. The pump is driven from the shaft G of the grinder by means of a belt passing over pulleys H and I. The water delivered by the pump K is supplied to the cylinders of the grinders through pipe line J.

This system is used only on grinders driven by hydraulic turbines. It is subject to speed variation when the load is re-

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moved from the hydraulic turbine, due to pocket charging. If, in a certain mill, the grinder line be operated at 230 r.p.m. and the normal operating cylinder pressure is 60 lb. per sq. in., a reference to the curve in Fig. 49[1] will show that the speed of the pump will have to be 1100 r.p.m., and the pulley ratio must be 1100 : 230, or 4.78 to 1. If one pocket of a two-grinder unit is opened for charging, $\frac{1}{8}$th of the load is removed from the turbine, thus allowing it to speed up. Since the pressure pump is belted

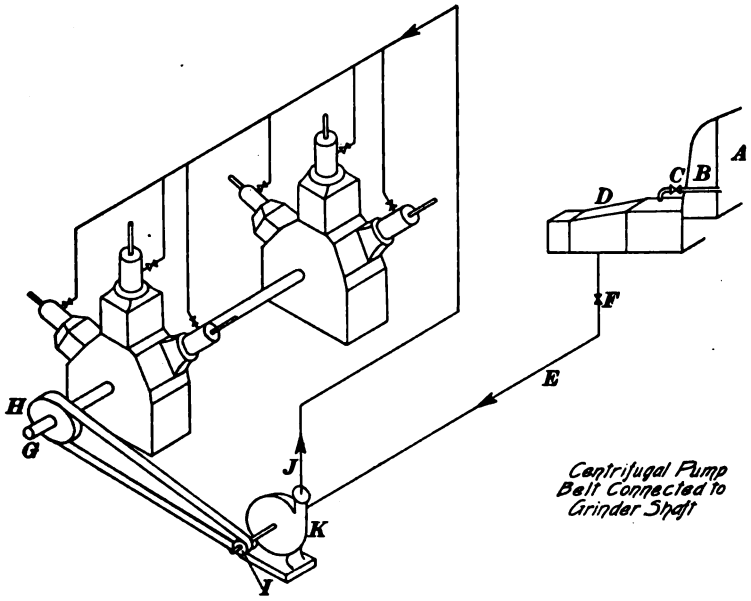

FIG. 48.

to the shaft, this speed increases so long as the friction load remains constant, and causes an increase in pressure in the grinder pipe line and of the wood against the stone, so the final pressure is 72 lb. per sq. in., and the corresponding speed of the grinder line is 246 r.p.m. If the cylinder pressure remained constant at 60 lb. per sq. in., and the power input also was constant, the final speed of the turbine would be about 278 r.p.m. The effect of the use of this direct-connected pump, therefore, is to reduce the speed variation of the grinder stones. This is because an increase in grinder speed immediately causes an increased pump speed,

[1] This curve was plotted from data given in the catalog of a manufacturer of pumps used for this type of service.

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which is reflected in higher pressure of wood on the stone, producing a greater braking effect which then slows down the grinder. The reader is referred to characteristic curves for medium speed, medium head, centrifugal pumps for further study of the action of this form of layout. These may be found in some of the standard mechanical engineering handbooks.

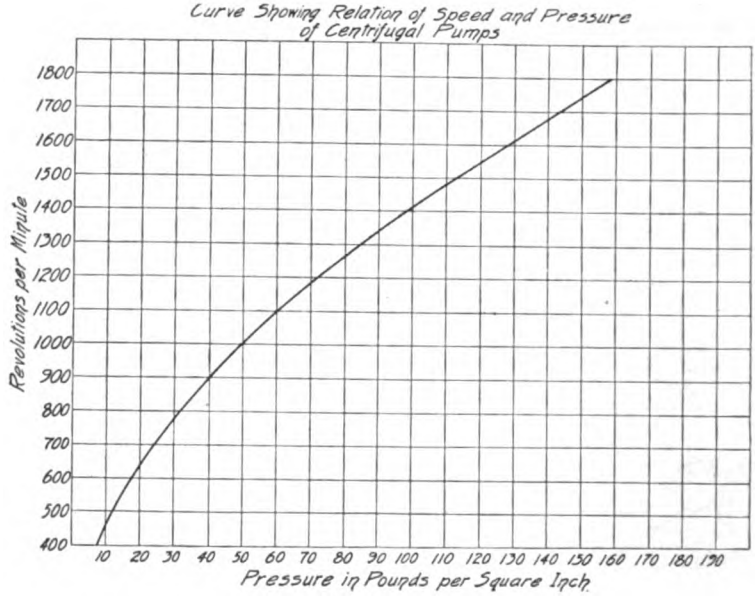

FIG. 49.

114. Constant-Pressure Centrifugal Pump, with Reducing Valve and Air Cushion.—Fig. 50 gives a diagrammatic layout of the system. It is the same one as included in Fig. 40. The centrifugal pump *K* in Fig. 50 operates at constant speed and maintains a delivery pressure somewhat in excess of what is required for the grinders. The reducing valve *G* is adjustable and controls the pressure in the grinder hydraulic cylinders. The water delivered to the grinders passes through pipe line *J*, into which is connected a tank *I*. This tank is kept about two-thirds full of air under the same pressure as the water. The object of this tank is to equalize the pressure of the water in the system when a large number of pockets are thrown off at the same time. Water being practically incompressible, the result of a large volume demand on the centrifugal pump would be a pressure drop

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in the system. The air expanding in tank *I* under these conditions causes a delivery through open valve *G* of the water stored in tank. The gauge glass *L* is used to indicate the water level in the tank.

This system has the advantage of being very flexible in use, prevents water hammer, and has a minimum of repair costs. It has the disadvantage of allowing speed variation, due to the constant-pressure water supply during pocket filling.

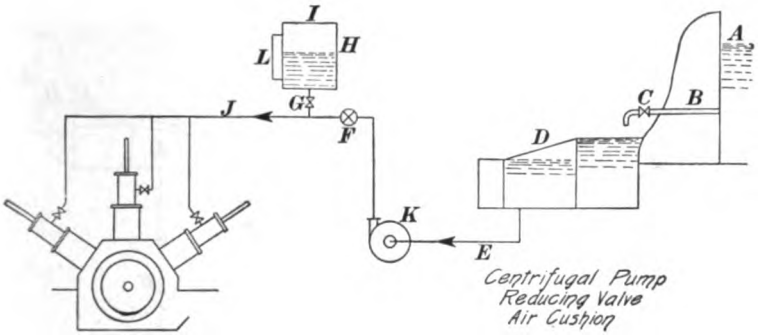

FIG. 50.

115. Special Grinder-Pressure Systems.—Considerable attention has been given during the past two years to improvements in the pressure systems used for hand-fed grinder operation. For the hydraulic-turbine driven equipment, the object has been to find the most efficient speed of rotation for the operating head and gate opening on the turbine, and then to keep the predetermined speed constant by varying the pressure in the hydraulic cylinders. In other words, the friction load on the turbine is maintained constant by varying the pressure in the hydraulic cylinder. Fig. 51 gives a general layout of a system of this type. Water is supplied to the suction side of centrifugal pump *K*, which operates at constant speed and delivers water at a pressure of 25–50 lbs. per sq. in. above the average operating pressure in the grinder cylinder. The air tank *F* performs the same function as in Fig. 50. The pressure-control valve at *G* varies the pressure in the grinder hydraulic-cylinders by throttling the high-pressure water that is delivered by the pump to the lower pressure at the discharge side *H* of the control valve *G*. The variation in the action of the control valve *G* is caused by the sprocket-and-chain drive, which connects shaft *I* to control-

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valve drive shaft at *J*. If one pocket goes off (jams, or is opened for charging), the small speeding up of the grinders, due to load decrease, operates the control valve *G*, thus putting more pressure in the remaining cylinders and tending to maintain constant the total friction load of wood on grinders.

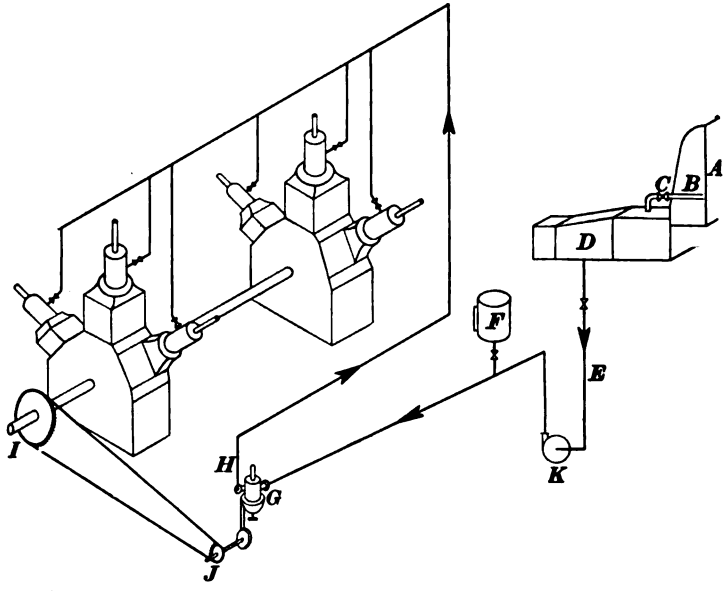

FIG. 51.

This system has many desirable features, and it is claimed that it saves as much as 15% of power and labor usually employed in the grinder department of mechanical-pulp mills.

For motor-driven grinders, there are several systems in use, the object being to maintain a more uniform load on the driving motor. The operation of these regulators is practically the same as the governor on magazine grinders, which has already been described.

QUESTIONS

1. Mention some factors which cause a variation in the power consumed in the production of the same quality of pulp in different mills.
2. What grade of stone and condition of surface is satisfactory for the production of newsprint pulp?

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3. What change in the method of dressing the stone might be made when producing pulp for wall board?

4. What quality of pulp is desired for the manufacture of manila paper?

5. (*a*) What is meant by brown pulp? (*b*) how is it produced? (*c*) what are its characteristics?

6. For what grade of paper would you advocate the use of pulp manufactured by the Friedsam process? Why?

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MANUFACTURE OF MECHANICAL PULP

EXAMINATION QUESTIONS

1. What would you consider an ideal pulp stone?

2. What precaution must be taken in setting a stone with regard to the direction of the threads on the shaft?

3. What practical conditions largely determine the location of mechanical pulp mills?

4. Explain (*a*) what you mean by uniformity of pulp. (*b*) How it is tested?

5. Describe a magazine grinder, and point out the differences between it and a hand-fed grinder.

6. Describe the different kinds of burrs, and mention the general effect of each on the character of the pulp produced.

7. How does the stone's surface affect, (*a*) yield? (*b*) quality of pulp? (*c*) horsepower per ton?

8. (*a*) How does temperature of grinding affect the quality of the pulp? (*b*) How is the temperature controlled?

9. Explain what would happen if there should be a stoppage of water to the grinder cylinders, with regard (*a*) to the pulp production; (*b*) to the effect on the turbine and (*c*) to the effect on the grindstone.

10. Draw up a diagram showing the various stages of the manufacture of mechanical pulp.

11. What items should appear on the record sheet of a mechanical-pulp mill?

12. What conditions should be maintained for the manufacture of pulp for cheap book paper?

13. What system of supplying high-pressure water to the grinder cylinders would you recommend for grinders direct-connected to hydraulic turbine? Explain your choice.

14. What main factors govern the power available for mechanical-pulp manufacture, where the grinders use water as a source of power?

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SECTION 4

MANUFACTURE OF SULPHITE PULP

By Bjarne Johnsen, Dr. Ing.

HISTORY AND OUTLINE OF THE PROCESS

HISTORY

1. Origin of the Process.—In 1866 and in 1867, the American Chemist, Benjamin Chew Tilghman, was granted English patents on a process of cooking wood with a solution of sulphur dioxide SO_2 in water, with or without the addition of the bisulphite of an alkali, such as calcium bisulphite $Ca(HSO_3)_2$ or magnesium bisulphite $Mg(HSO_3)_2$. The object of this process was to produce from wood a fibrous material suitable for the manufacture of paper, by removing from the wood the incrusting materials and recovering the pure fiber. These patents were the results of extensive experiments carried out by B. C. Tilghman and his brother, R. Tilghman, at the pulp and paper mills of W. W. Harding & Sons, in Manayunk, near Philadelphia.

In his first attempts at cooking the wood with a solution of sulphur dioxide SO_2 in water at a high temperature and pressure, Tilghman obtained a pulp of dark color, which was very difficult to bleach. He discovered that the water liquor from this cooking process contained large quantities of sulphuric acid, and he attributed the poor color of the pulp to the action of this acid. He therefore added lime to the cooking acid, in order to neutralize the sulphuric acid formed during the cooking process, and the result was a pulp of light color and easy bleaching quality.

2. Paper makers who visited the mills at Manayunk at that time reported that experiments with the new process were made on a large scale and that a good grade of pulp was obtained. The

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large-scale experiments were carried out in a horizontal cylinder, 50 feet long, with a diameter of 3 feet. This digester was made to rotate; it was lined with lead and was equipped with a worm of lead plate, which should act as a conveyor of the pulp during the rotation of the digester. The idea was to produce the pulp in a continuous process, the wood and liquor being forced through the digester, according to the counter-current principle.

3. It is obvious that enormous difficulties would be experienced with an experiment of this kind; and the reason why Tilghman was not able to make his process a commercial success must be attributed to the difficulties he had in preventing leakage, at the high pressure of 80 pounds, with this impractical equipment. Later on, he used a spherical digester, which proved to be more satisfactory.

But, at that time, there was a drop in the price of soda, which made it possible to manufacture soda pulp at a low cost; and fearing the competition of the soda process under these circumstances, Tilghman decided to discontinue his experiments, after having spent several years and a fortune on the solution of the problem.

4. It is of historical interest to remember that Tilghman's English patents included the cooking of wood with a solution of sulphurous acid and calcium bisulphite or other base. The patents also included recovery of the sulphur dioxide gases at the end of the cooking process, by absorbing them in water. It was also intended to utilize the waste liquor as a fertilizer or a binding material.

Tilghman cooked spruce, hemlock, poplar, and willow, and his method of cooking was to boil the charge of wood and acid at 127°C. for 6 to 8 hours.

5. Making the Process a Commercial Success.—The Swedish chemist, C. D. Ekman, deserves the credit of having made the sulphite process a commercial success. Probably ignorant of the Tilghman patents, he had developed a process of cooking wood with a magnesium bisulphite solution $Mg(HSO_3)_2$, and started up the first sulphite mill in the world at Bergvik, Sweden, in 1874. This mill was equipped with six small rotating digesters, heated indirectly by means of a steam jacket and having a capacity of about 800 pounds. The annual production of this mill was, in 1875, about 485 tons, and paper made from this sulphite

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pulp is still in existence. In 1876, Ekman published a pamphlet in Swedish, English, and German giving instructions for the use of this new product in the manufacture of paper.

At the same time the German chemist, A. Mitscherlich, was developing a sulphite process; but the experiments on a large scale were not entirely satisfactory in the first few years. It was not until 1880, that licensees of the process were able to produce commercially a pulp of good quality with Mitscherlich's process, which really differed from the practical operation of the original Tilghman process only in that the wood was cooked at a low temperature and pressure and, therefore, more slowly. The heating of the wood and acid was done indirectly by means of steam-heated copper pipes, placed at the bottom of the digester.

In Austria a sulphite process was developed by Eugen Ritter and Carl Kellner; it was operated secretly in their mills from about 1878, and was protected by an Austrian patent in 1882. Steam was admitted directly into the digester, and the time required for bringing the digester up to high temperature, and thereby the total cooking time, was considerably reduced.

In America, the sulphite process was introduced by Charles S. Wheelwright, who operated the Ekman process in the plant of the Richmond Paper Company, where he introduced many improvements in the manufacturing operations.

Aug. Thilmany, who had bought the Mitscherlich patent for America and, in 1887, transferred the rights for United States and Canada to the International Fiber and Paper Company, directed the building of the first Mitscherlich mill in the United States for Geo. N. Fletcher and Albert Pack, in Alpena, Michigan. The Ritter-Kellner process was brought to this continent by Governor Russel and Charles Riordon, who built the first mill in Canada at Merritton, Ontario, in 1885.

6. Much credit is due to the pioneers in this industry and to the men who, during the comparatively short history of the sulphite process, have assisted in overcoming the technical difficulties of the early days and who, by the introduction of practical improvements in the processes, have made possible the development of the industry to its present importance. The annual production of the sulphite-pulp mills in the United States in 1920 was 1,576,576 tons and in Canada, 610,585 tons.

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OUTLINE OF THE PROCESS

7. Flow Sheets.—In diagram, Fig. 1, are show the flow sheets, which give the course of materials through the processes of conversion. Referring to (*a*), sulphur in the form of brimstone (S) or pyrites (FeS_2) is burned in a sulphur burner or pyrites furnace, forming sulphur dioxide gas SO_2. When using sulphur, the burning is completed in a combustion chamber; when pyrites are burned, a scrubber removes injurious dust. The gas is

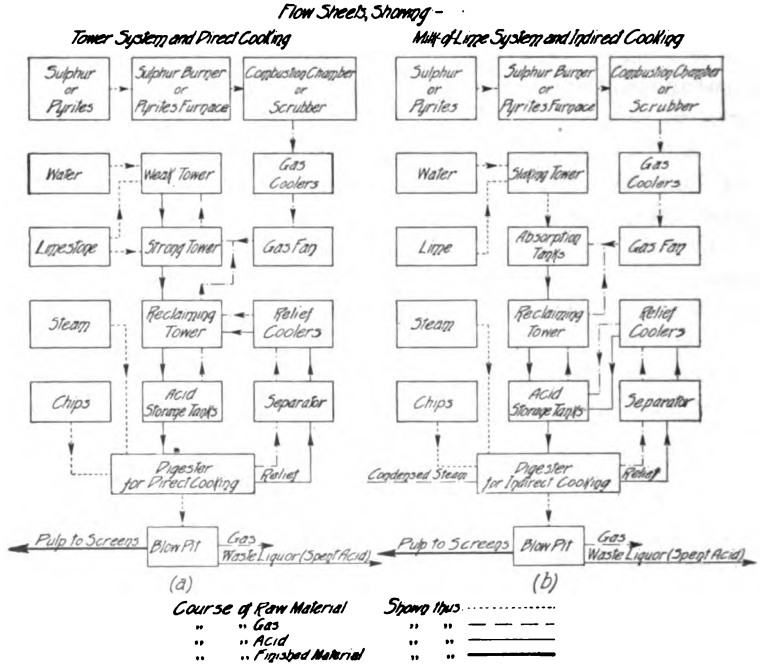

FIG. 1.

cooled and passed into the bottom of the strong tower, and is mostly absorbed by combination with the limestone therein, in the presence of weak acid that trickles over the stones, forming *strong acid*. The weak gas escaping from the strong tower enters the weak tower, also charged with limestone, when it combines with the limestone and the shower of water, forming *weak acid*, which then passes to the strong tower. The strong acid goes to the reclaiming tower, to be fortified by suphur dioxide that is

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relieved from the digester during cooking. The relief gas is cooled before it enters the reclaiming tower, and the relief liquor is usually passed through a separator, which separates the gas from the liquor, the gas, and sometimes the liquor, being returned, after cooling, to the acid system. The *fortified* or *cooking acid* is then stored for use in the digester, into which the proper amount is fed along with the chips, and the cooking is done by introducing steam, which, in direct cooking—as here assumed—mixes directly with the *digester charge*. When the cooking is finished, excess pressure is relieved (relief handled as above), and the pulp, waste liquor, and gas are forced into a blow pit. Steam and gas escape by a vent, waste liquor drains through the perforated false bottom, and the pulp is washed and pumped to the screens (as described in the Section on *Treatment of Pulp*).

Figure 1 (*b*) differs from (*a*) in that lime, instead of limestone, is used; this is treated with water in a slaking tank, to make *milk of lime*, which is used in an absorption tank or tower system to make strong acid, and which is fortified as above described, to make cooking acid. Chips and acid are charged into the digester; but in indirect cooking—assumed for this case—the steam does not mix with the charge; it enters a coil in the digester, which accounts for the condensate (condensed steam) noted in the diagram. *Pulp*, *waste liquor*, and *gas* are handled as described.

Either form of sulphur, either form of acid apparatus, and either form of digester may be combined, as desired.

PREPARATION OF THE COOKING ACID

8. The preparation of the bisulphite liquor for the cooking process consists of (*a*) The burning of sulphur or pyrites; (*b*) the absorption of the resulting sulphur dioxide (SO_2) gas in a milk-of-lime solution or in water in the presence of limestone; and (*c*) the strengthening of the acid with sulphur dioxide recovered from the cooking process. The raw materials used in this process are sulphur or pyrites and lime or limestone.

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RAW MATERIALS

SULPHUR

9. Occurrence and Properties.—Sulphur is a brittle, pale yellow solid. It melts at 113°C. to a mobile liquid of an amber color, but upon further heating it becomes thick; at about 200°C., it is so thick that it will not flow and has assumed a dark color; at 350°C., the sulphur again becomes fluid, but retains its dark color. Sulphur ignites at 248°C. and boils at 445°C., giving off dark brown vapors, which upon cooling, are condensed to a fine yellow powder called **flowers of sulphur** or **sublimed sulphur. Brimstone,** or **roll sulphur,** is formed by melting sulphur and casting it in sticks.

There are other modifications of sulphur, which, however, are not of particular interest in acid making. The chemical symbol for sulphur is S, its atomic weight is 32.07, or roughly, 32; and one atom of sulphur will combine with two atoms of hydrogen or with one atom of a bivalent metal, forming so called *sulphides.* But the valence toward oxygen is variable. The most important of the oxygen combinations are sulphur dioxide SO_2 and sulphur trioxide SO_3, which form with water sulphurous acid H_2SO_3 and sulphuric acid H_2SO_4 respectively. Other combinations of sulphur, oxygen, and water are known as

Thiosulphuric acid ..... $H_2S_2O_3 = (S_2O_2 + H_2O)$
Dithionic acid..... $H_2S_2O_4 = (S_2O_5 + H_2O)$
Trithionic acid..... $H_2S_3O_6 = (S_3O_5 + H_2O)$

10. The main sources of sulphur, as far as the sulphite pulp industry of the United States and Canada is concerned, are Louisiana and Texas, where it is found in free form about 600 feet and more below the surface. It is recovered in enormous quantities by melting with superheated water and pressing it to the surface by means of hot compressed air, and requires no further purification. Some sulphur is imported from Japan.

11. Sulphides.—Sulphur also occurs in nature in combination with metals as sulphides, such as iron sulphide, or **pyrites,** FeS_2, which according to the formula contains 53.46 per cent sulphur and 46.54 per cent iron; but it is only seldom found in nature in this high purity. Usually, it occurs in mixture with sulphur compounds of other metals, such as copper, zinc, lead, etc.,

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partly as sulphates and partly as sulphides, and the value of the ore for the sulphite pulp industry depends very much upon the quantity and nature of the accompanying metals. None of the other natural sulphides are so high in sulphur or part with it so easily as iron sulphide. Copper sulphide is detrimental, not only because it lowers the percentage of total sulphur in the ore but also because its greater fusibility makes it more difficult to regulate the temperature of roasting. Pyrites containing more than 8 per cent copper can be profitably employed only under very exceptional cirumstances.

Lead sulphide also increases the fusibility and reduces the yield of sulphur in the roasting process, since it forms sulphate, which remains as such in the cinders. A good pyrite should be nearly free from lead, zinc, arsenic, antimony, and selenium. Regarding the last, it is well known that the presence of even very small quantities may cause serious trouble in the sulphite cooking process.

The value of pyrites as compared with sulphur is of course determined by the price of recoverable sulphur at the mill, which again depends not only upon the location of the mill but also upon the chemical composition, as discussed above.

LIMESTONE AND LIME

12. Limestone.—The appearance of a limestone depends upon the purity of the stone. In its purest form, the stone is white and crystalline, and it consists, practically, only of calcium carbonate $CaCO_3$, as, for instance, in marble. But the stone usually contains impurities, such as oxides of iron and aluminum and insoluble silica, which affect the appearance of the stone. This varies from the highly crystalline variety to the amorphous, porous stone, while the color may vary from white to yellow and grey. Also, the specific gravity varies, and is highest with the highly crystalline stone. The solubility of the limestone in sulphurous acid increases with the crystalline character and, of course, with the strength of the acid. Usually, the limestone contains magnesium carbonate $MgCO_3$, and the properties of the stone vary according to the amount of magnesia.

13. Dolomite is a calcium-magnesium carbonate, normally containing 54.27% calcium carbonate and 45.73% magnesium

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carbonate. But a stone containing one $MgCO_3$ to two $CaCO_3$ is also called dolomite.

Limestone and dolomite are found in many places in the United States and Canada and in many different qualities. The variations in the composition of such stones are shown in the following table:

	$CaCO_3$	$MgCO_3$	Fe_2O_3 and Al_2O_3	Insoluble matter
Average Portneuf Co., Canada	95.80	1.30	0.60	1.25
Average Lake St. John, Canada	85.90	1.95	0.95	9.10
Marble Stone, U. S.	99.05	.....	0.11	0.40
Bleachville, Ont., limestone	97.63	.....	0.22	0.13
White Rock, Ohio	58.62	37.82	0.97	0.70
Portage du Fort	55.76	43.40	0.12	0.68

14. Lime.—Lime CaO is obtained by burning limestone, and the composition therefore depends upon the quality of the limestone.

The reaction is expressed by the equation.

$$CaCO_3 + \text{heat} = CaO + CO_2.$$

While a low magnesia content, preferably not above 5 per cent, is considered the most suitable for the tower system, a high magnesia lime is preferred in the milk-of-lime systems. The composition of limes used in acid making is given in the following table:

	(1) Per Cent	(2) Per Cent	(3) Per Cent
Calcium oxide, CaO	56.02	58.61	55.96
Magnesium oxide, MgO	40.10	40.25	37.98
Alumina and ferric oxide, Al_2O_3 and Fe_2O_3	0.57	0.12	1.23
Sulphur trioxide, SO_3	0.11	0.15	0.16
Insoluble in HCl	0.94	0.07	1.51
Silica soluble in acid, SiO_2	0.47	0.15	1.81
Loss on ignition, H_2O, CO_2, etc	1.43	0.51	1.00

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PREPARATION OF SULPHUR DIOXIDE

15. When sulphur or a sulphide burns, it combines with the oxygen of the air to form oxidation products of sulphur, mainly sulphur dioxide SO_2. The nature of the gas, the proportion of the sulphur dioxide to the other combinations of sulphur and oxygen, depends upon the prevailing conditions, such as the temperatures to which the gases are exposed and the proportion of sulphur gases to oxygen or air. In other words, the quality of the gas depends upon the construction and the operation of the sulphur burner or the pyrites furnace.

SULPHUR BURNERS

16. Flat Burner.—The flat type of sulphur burners is essentially a retort, to which the sulphur is fed intermittently through a door at the front. The retort itself is a one-piece iron casting, about 8½ feet long and 3½ feet wide; the cross section forms an arch with the highest inside dimension of 18 inches. The gases leave through an 8-inch pipe, which is usually bolted to the back of the furnace. To the open front of the furnace is bolted a second casting, which carries the door. The furnace rests on a brick foundation, and it is usually placed on rollers, to permit free expansion and contraction. The capacity of these burners is only about 5 pounds of sulphur per square foot of surface per hour, and they require, therefore, much floor space. Unless the flat burners are equipped with rakes to agitate the surface of the molten sulphur, they are inefficient, since the sulphur often contains a small quantity of oil, which during the process of burning forms a layer on the surface resembling asphalt, and this layer prevents the free contact of sulphur and air.

The flat burners have now almost disappeared from the sulphite mills, and modern plants are usually equipped with the more efficient rotary burner or the stationary vertical type.

17. Rotary Burner.—This consists (see Fig. 2) of cast-iron or steel cylinders *A*, to which are riveted the conical ends *B*. The burner rests on rollers *K*, which are revolved by means of gears, which give the horizontal cylinders a slow rotating motion of about 1½ revolutions per minute. The burners are built in different sizes, depending upon the requirements of the mill,

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two burners 4 feet diameter and 15 feet in length being sufficient for a 100-ton mill.

The front cone of the burner has a damper *F*, Fig. 2 (*c*), to regulate the admission of air; it is also equipped to receive the sulphur, either in solid form, by means of a worm from a hopper placed immediately in front of the burner, or in melted form, through a pipe *C* extending through the axis of the burner. In the latter case, the sulphur is often melted in a tank *D*, equipped

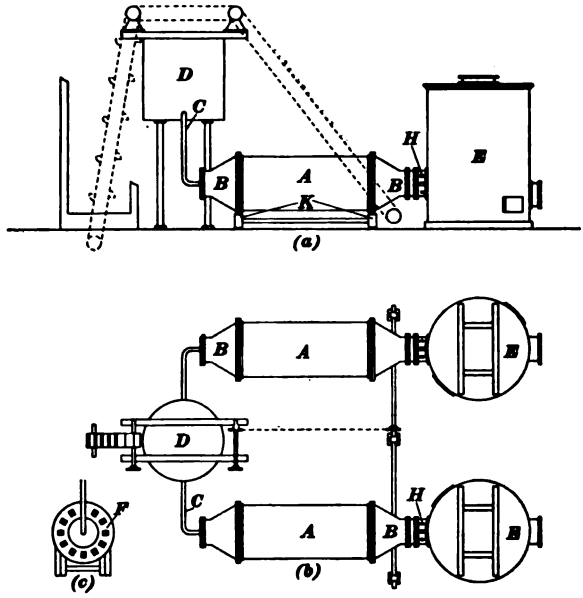

FIG. 2.

with steam coils, from which the molten sulphur flows to the various burners. But many mills have placed the melting tank just above each individual burner or over the combustion chamber, thus utilizing the heat from the burner and decreasing the steam consumption for this purpose considerably.

When the burner revolves, the molten sulphur adheres to the side of the cylinder and is carried some way up the side before it drops back, thus increasing the surface of the sulphur mass exposed and giving efficient combustion. The rear cone is connected up to a short pipe line leading to the combustion chamber *E*, which is a large steel chamber in which the gases from the burners are mixed thoroughly with air, in order to

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secure complete combustion of the sulphur, which vaporizes, but does not have time to turn in the rotary. An auxiliary damper *H* between the rotary and the combustion chamber enables the operator to admit and regulate the extra air necessary for complete combustion.

18. It is a very easy matter to start up a rotary sulphur burner. If the sulphur is fed to the burner in solid form, the fire is started by throwing into the burner some rags soaked in oil, and then gradually feeding the sulphur. With liquid sulphur feeding, the sulphur in the melting tank must at first be heated to the melting point by admitting steam to the coils; at the same time, the sulphur in the pipe lines leading from the melting tank to the burner must be melted by applying a torch or a gas burner. In starting up, time may be gained by heating the burner itself with direct fire.

19. Stationary Sulphur Burner.—The vertical, stationary burner known as the **Vesuvius burner,** Fig. 3, consists of an upright cylindrical steel shell, lined with fire brick, and equipped with four trays, one above the other. On the top is a large melting kettle *A* for sulphur, with a needle valve *B* in the bottom. The valve can be adjusted so as to admit a certain quantity of sulphur to the trays. The burner is started by building a fire on the top tray *C*, whereby the sulphur melts in the kettle; and by opening the needle valve a little, sulphur drops into the top tray *C*. When the top tray is full, the sulphur overflows into the next tray, from which it again overflows on the *opposite* side into the third tray. Each tray has a door and a damper *D*, to admit the required amount of air. The ashes collect at the bottom *E* of the burner, while the gas leaving the top tray passes through the combustion chamber attached at *F*, and sufficient air for complete combustion is admitted at damper *H*. Regulation of draft is possible both by the opening of tray doors and by the damper *K*. This burner takes up very little space, requires no power and works automatically when once started.

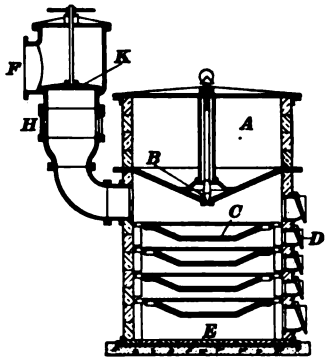

FIG. 3.

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BURNING OF PYRITES

20. Reason for Burning Pyrites.—Owing to the comparatively low sulphur prices and the simplicity of the process of sulphur burning, only very few sulphite mills on the American continent have used pyrites for the production of sulphur dioxide. But there are numerous deposits of pyrites in both the United States and in Canada; and with the modern types of furnaces, the roasting process is very simple and efficient. So it is actually only a question of the price of sulphur at the mill as compared with that of the pyrites ore, whether it would not be an economical advantage to replace the sulphur with pyrites.

Of the many types of furnaces, the Herreshoff furnace and the Wedge furnace are most commonly in use in sulphuric acid plants in America and in Europe, as well as in European sulphite mills.

21. Herreshoff Furnace.—The Herreshoff furnace, Fig. 4, consists of a steel cylinder *A* lined with red brick *B*. It is divided by arches *C*, of fire brick, into several compartments, one on top of the other. The top of each of the arches forms a hearth upon which the ore is burnt.

Through the center of the furnace runs a hollow shaft *D*, which is driven by means of gears *E* at the base, so as to make one revolution in two minutes. For each chamber, two horizontal arms *F* are attached to the central shaft, with lugs fitting into sockets on the shaft, and are held in place by their own weight. It is an easy matter to renew the arms during the operation of the furnace. The ore is fed automatically to the top chamber from a hopper *K* on the top of the furnace, and is distributed on the hearth. The rabbles (teeth) of one of the arms are set at such an angle that the ore is moved toward the center, while the position of the rabbles on the second arm causes the ore to turn over, whereby a large surface of the ore is exposed to the air. Arriving at the center of the top chamber, the ore drops through an opening into the chamber below, in which the rabbles slowly work the ore towards the outer edge of the hearth, where it drops into the chamber underneath; on the next, it is worked to the center, and so on, until the ore finally has passed through all chambers, and is discharged as cinder to the bottom shelf or chamber. The air is admitted through openings around the bottom hearth, and passes through

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all the chambers in the direction opposite to that of the ore. The quantity of air is so regulated as to secure the proper com-

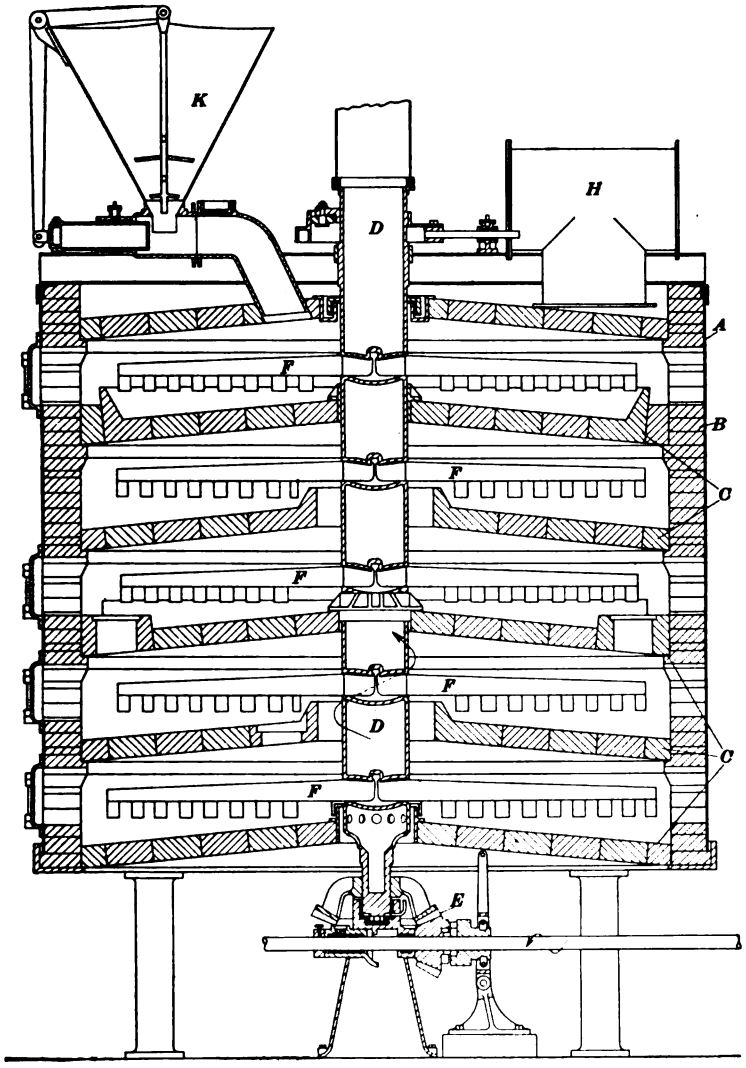

Fig. 4.

bustion of the sulphur, so that the gas leaving the furnace from the top chamber at *H* carries the desired quantity of sulphur dioxide. The hollow central shaft and also the arms are cooled

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with air. The small-size furnaces, of about 11 feet diameter, require 1 to 2 horsepower and will roast from 3 to 4 tons of pyrites in 24 hours. The larger size furnace, 16 feet in diameter, will roast about 9 tons in 24 hours. In the modern type of furnace, the individual rabbles can be replaced, and the cooling air to the shaft and arms can be regulated, so as to permit an effective control of the temperature within the furnace.

22. Wedge Furnace.—The Wedge furnace is very similar to the Herreshoff furnace in construction, but possesses certain characteristic features. The central shaft, which makes about 1 revolution in 4 minutes, has a diameter of 5 feet and is open at top and bottom, allowing air to circulate. It is sufficiently large and cool for a man to enter during the operation, for repair of the arms. The outside of the shaft, which is made of riveted steel plate, is protected by fire brick. The rabble arms are hollow and are equipped with pipes for air as well as water cooling. The furnace has 7 horizontal hearths. The ore is automatically fed to the hopper and drops to the top shelf, where it is stirred by special rabbles and dried by the heat from the furnace. From this shaft, the dried ore drops to the center of the top hearth, and is slowly conveyed by the rabbles toward the periphery, as in the Herreshoff furnace. The cinder is discharged from the bottom hearth. The capacity of the furnace varies from 23 to 33 tons of ore in 24 hours. One furnace of the largest size would be sufficient for a 100-ton mill, assuming a sulphur content of 35 to 40 per cent of the ore and a sulphur content in the cinder of about 2 per cent. However, it is advisable to install two furnaces, to allow for repair shut-downs.

Another type of furnace is similar to the rotary furnace described in the Sections on *Soda Pulp* and *Sulphate Pulp*. The pyrites, which must be thoroughly dry in any case, fall in a shower, as the furnace rotates, through the current of air passing through the furnace.

23. Starting a Pyrites Furnace.—The starting up of a pyrites furnace is more difficult than to start a sulphur burner and takes considerably more time, depending, of course, upon how long the furnace has been down. Before any ore is admitted, the furnace has to be brought to the required temperature for roasting, by maintaining a good fire in the furnace. When the desired temperature is reached, the pyrite, which has been dry-

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ing in the top chamber, is gradually fed to the furnace, and the air is regulated by means of the dampers, as well as by the gas pump or fan.

BURNER GASES

24. Quantity of SO_2 Formed.—In the sulphite process, it is the object of the sulphur burning to form as much sulphur dioxide as possible, and to prevent the formation of other combinations of sulphur and oxygen. When, in the burning process, the sulphur unites with the oxygen of the air to form sulphur dioxide, according to the equation,

$$S + O_2 = SO_2,$$

one volume of oxygen forms an equal volume of sulphur dioxide. The volume of sulphur dioxide in the gas leaving the burner can therefore never be higher than the volume of oxygen present in the air supplied to the burner. Air contains about 21 per cent oxygen and 79 per cent nitrogen by volume, and the maximum SO_2 content theoretically obtainable in the burner gases is therefore 21 per cent. But a gas of this strength is never obtained in practice; it varies usually between 14 and 18 per cent, depending upon the operation of the burner and the method of cooling the gases. The regulation of the air supply to the burner is the most important factor in this operation, since upon the air supply depends the extent to which the sulphur is oxidized and the extent to which the gases are diluted with excess air.

If an insufficient quantity of air is admitted, sulphur will evaporate and condense in the coolers, in the form of sublimed sulphur, which will cause serious difficulties in clogging up the pipe lines; or it may partly reach the absorption system and seriously interfere with the cooking process. In either case, it means a direct loss in sulphur.

26. Combustion Chamber.—It is the principal object of the combustion chamber, Fig. 5, to assist in preventing sublimation, by completing the combustion of the sulphur. This is nothing but a large steel chamber, lined with brick that is backed with fire clay, located closely behind the burner, in which the gases are intimately mixed, and is equipped with dampers (*H*, Figs. 2 and 3) for admittance of air, if required. The combustion chamber has also one or more baffle plates or walls, to hold back

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any dust particles and to assure effective mixing of the gases. In a great many mills, the value of the combustion chamber is not sufficiently recognized, and it is often built too small. In Fig. 5, the gases enter at *E*, pass through the baffle wall by the holes *W*, and leave by outlet *F*. *K* and *L* are cleanouts.

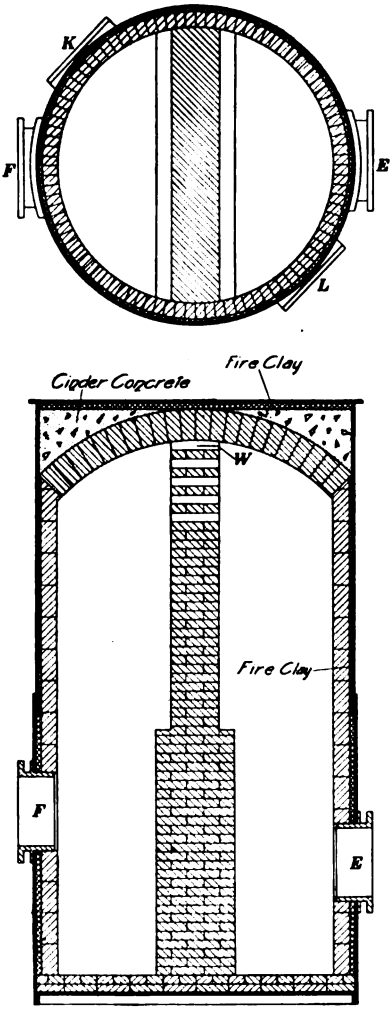

FIG. 5.

27. Effect of Temperature.—The temperature of the gas as it leaves the combustion chamber and enters the cast-iron pipe that connects it with the coolers is usually from 700° to 900°C. It is important to keep the temperature at this point, in order to avoid the formation of any large amount of sulphur trioxide gas SO_3, which is always formed to some extent in the sulphur burning process. It is important to keep the SO_3 content of the gas as low as possible, since it combines with the calcium in the absorption system, forming calcium sulphate $CaSO_4$, which is an insoluble salt, and which represents a direct loss of sulphur. The presence of sulphuric acid in the digester is also detrimental to the fiber in the cooking process.

The formation of sulphur trioxide SO_3 according to the equation

$$SO_2 + O = SO_3$$

depends in the first place upon the temperature. It is found that between 400° and 600°C., the maximum of SO_3 is produced;

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while at temperatures below 200°C. and around 900 to 1000°C., practically no SO_3 is formed. It is therefore important to avoid the critical temperatures as much as possible; or, in other words, to keep the temperature in the combustion chamber high, and to cool the gases after leaving this chamber as quickly as possible.

28. Importance of Regulating Air Supply.—The rapidity with which the sulphur dioxide is oxidized to trioxide is also increased in the presence of much oxygen, and a large excess of air should therefore be carefully avoided.

The correct amount of air required per pound of sulphur in order to produce a gas of a certain strength can easily be calculated. In the following example, a strength of the burner gas of 16% is assumed, and it is assumed that there is no sublimation and no SO_3 formation.

According to the formula,

$$\begin{array}{ccccc} S & + & O_2 & = & SO_2 \\ 32 & & 32 & & 64 \end{array}$$

One *molecule* of oxygen O_2 is used in the formation of one molecule of sulphur dioxide SO_2, or a certain volume of oxygen gives an equal volume of SO_2. On the other hand, one *pound* of sulphur combines with one pound of oxygen forming *two* pounds of sulphur dioxide. Or, one pound of sulphur reacts with one pound of oxygen, giving a volume of 11.75 cu. ft. at 20°C. and atmospheric pressure, producing a burner gas containing 11.75 cu. ft. of SO_2.

Since the strength of the burner gas is assumed to be 16% 11.75 cu. ft. of oxygen required to produce this strength represents 16% of the total air admitted, assuming all the oxygen to be converted to sulphur dioxide. (In practice, a slight excess is required.) Therefore,

$$\text{volume of air} = \frac{11.75}{0.16} = 73.4 \text{ cu. ft}$$

The air and sulphur should be as dry as possible, since the presence of moisture encourages the formation of sulphuric acid.

GASES FROM PYRITES FURNACE

29. Amount of SO_2 Obtained from Pyrites.—When sulphur dioxide is formed from pyrites, the following reaction takes place.

$$2FeS_2 + 11O = Fe_2O_3 + 4SO_2$$

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In this case, one portion of the oxygen is consumed in the oxidation of iron to iron oxide, and, from the equation, it is seen that, with pure pyrites, 3 volumes of oxygen are used in this oxidation for every 8 volumes of oxygen required in the formation of sulphur dioxide. In order to produce the same amount of sulphur dioxide, correspondingly more air is required in burning pyrites than when elementary sulphur is used, and the gases are accordingly more diluted with the extra nitrogen introduced.

While the strongest gas theoretically obtainable in the burning of sulphur is 21% (air contains about 21% of oxygen), the theoretically strongest gas with pyrite is 15.3% sulphur dioxide. In practical operation, a 12 to 14% gas may be obtained with modern equipment. The volume of air per pound of pyrite naturally depends very much upon the composition of the ore, which also determines the consumption of oxygen.

30. Effect of Catalyzers on Amount of SO_3 Produced.—The quality of the gas leaving the furnace is also more variable than

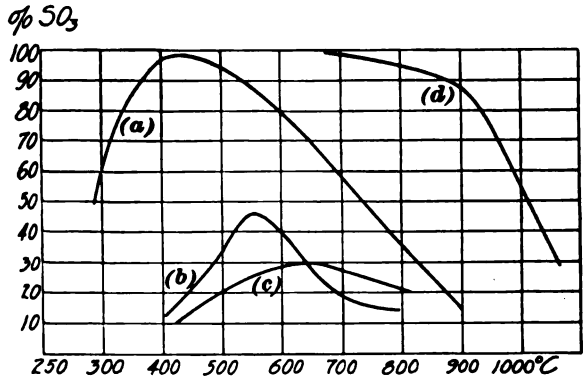

FIG. 6.—Effect of Temperature and Contact Substance upon the Formation of SO_3 (percentage of SO_2 to SO_3).

(*a*) No contact substance.
(*b*) Contact with cinder from furnace (Fe_2O_3·CuO).
(*c*) Contact with platinum.
(*d*) Stability of SO_3 in absence of contact substance (SO_3 decomposes at high temperatures to $SO_2 + O$).

that from the sulphur burners, and it requires a special purification. The gas usually carries with it considerable quantities of mechanical impurities, which have to be removed in so-called *dirt catchers* or *dust chambers*, or by filtering, or by electrical precipi-

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tation. The amount of SO_3 is also usually much higher, and it has to be removed in a special washing process; this is due to the fact that sulphur dioxide is more easily oxidized to sulphur trioxide in the presence of certain substances, as iron oxide. In the burning of sulphur, the only so-called catalyzer present is the metal of the burners and the piping; while in the pyrite process, the ore itself acts as a contact substance and accelerates the formation of SO_3, even at the lower temperatures.

The curves shown in Fig. 6 will give an idea of the action of such contact substances.

31. Removal of SO_3 from Gases.—The SO_3 is usually removed in gas washers or scrubbers, which are nothing but chambers of lead, in which the gases meet with a fine spray of water. The SO_3 is easily absorbed; but only a small proportion of SO_2 is absorbed, due to the low solubility of this gas at high temperature.

32. Also, electrical precipitation according to the Cottrell process is used in some mills. Recently, it was suggested that the gas be filtered through sawdust. The SO_3 and sublimed sulphur are absorbed by the sawdust, and other oxidation products, such as sulphur sesquioxide S_2O_3 and polythionic oxides (S_2O_5 and S_3O_5), are decomposed by the SO_3, which is already absorbed by the filter, into SO_2, which follows the gases, and into SO_2 and S, which are retained by the sawdust. This prevents the formation of these products in the cooking acid, where the SO_3 and, especially, the finely divided sulphur are extremely injurious in the subsequent cooking process.

COOLERS

33. Types of Coolers.—It was already mentioned that a rapid cooling of the gas is very important in the production of a pure gas. At high temperature, the dry gas may be passed through cast-iron pipes; in some mills, these pipes are made rather long, allowing the gas to air-cool to some extent before it reaches the actual gas coolers. This is not good practice, since there is a danger of keeping the gas too long at the critical temperature for the formation of SO_3. It is better to make the connection between the sulphur burners and gas coolers as short as possible and to make the cooling as rapid as possible.

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34. There are several types of coolers in use. In many mills a pond cooler is used, consisting of 6-inch lead pipes arranged parallel to one another and connected with flanges to lead headers. The whole system being placed in a pond, the gas enters at one header and passes through the pipes, leaving at the opposite header, while the cooling water is running in the opposite direction, cooling the outside of the pipes. With good circulation of the water, a fairly good cooling is obtained; but it is obvious that with this method, the cooling water is not used to its fullest advantage, since the water nearest to the pipes will receive most of the heat.

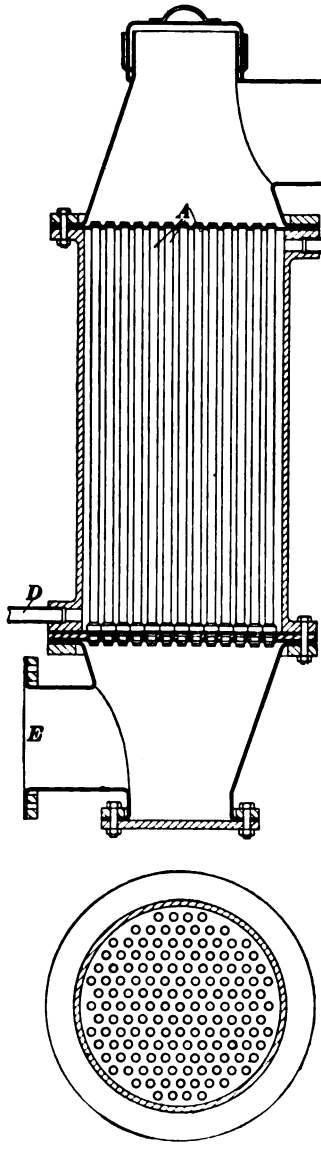

FIG. 7.

35. A more efficient cooler is a combination of the submerged, horizontal-pond cooler and a vertical cooler consisting of vertical lead pipes connected at the top by U bends. The water is sprayed onto the pipes at the top, and flows down along the pipes, forming a thin film around the pipes. With this cooler, the gas may be cooled nearly to the temperature of the water. A cooling system of this type is shown at *D* in Fig. 13.

36. A still more efficient cooler is the patented cooler, Fig. 7, in which a great number of 1-inch lead pipes *A* are arranged vertically, and are connected to headers at top and bottom. The cooling water enters at *C*, at the top of the cooler, and leaves at

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D, at the bottom of the cooler; the gas enters the bottom header at *E*, leaving through the top header at *F*. This cooler offers a larger cooling surface for the gas and uses much less water than those already mentioned. It may be considered a disadvantage of this cooler that the rather narrow pipes may be plugged, in case of much sublimation of sulphur.

37. In order to obtain an effective mixing, and consequent cooling of the gas, a new cooler has recently been developed. It

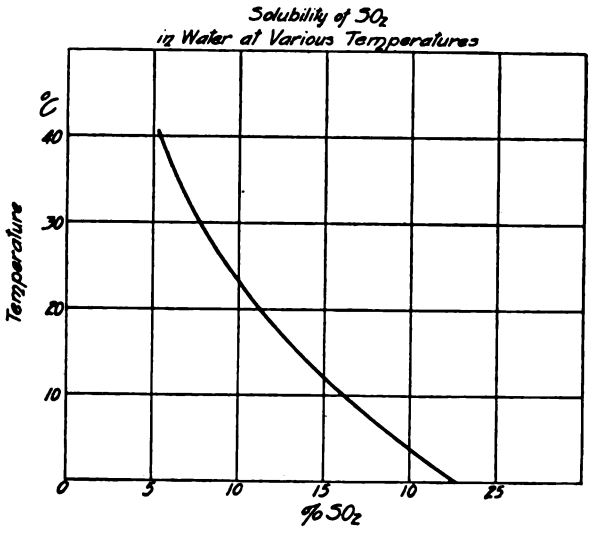

FIG. 8.

consists of corrugated lead plates, connected up to headers and forming chambers, through which the gases pass while the water flows on the outside. The corrugated sides effect an intimate mixing of the gases and afford a large cooling surface.

The important point with a cooler is that it have sufficient capacity, both with regard to cooling surface and to diameter of the pipes. If the cooler is too small to permit the free passage of the gas, the result may be overheating in the burner, with sublimation, and high vacuum on the line behind the cooler.

38. Main Object of Cooling Process.—While a rapid cooling of the gases is important in order to avoid the formation of large amounts of SO_3, the main object of the cooling process is to bring the temperature of the gas down to a point at which the

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SO_2 is easily absorbed by the water. The solubility of the sulphur dioxide in water is greatly dependent upon the temperature and also upon the pressure. This is shown in the preceding and following charts, Figs. 8 and 9.

From these charts it is obvious that at low temperature and high pressure the same quantity of water will dissolve a larger amount of gas than at high temperature and low pressure. In Fig. 9, the pressures are given in millimeters of mercury and their

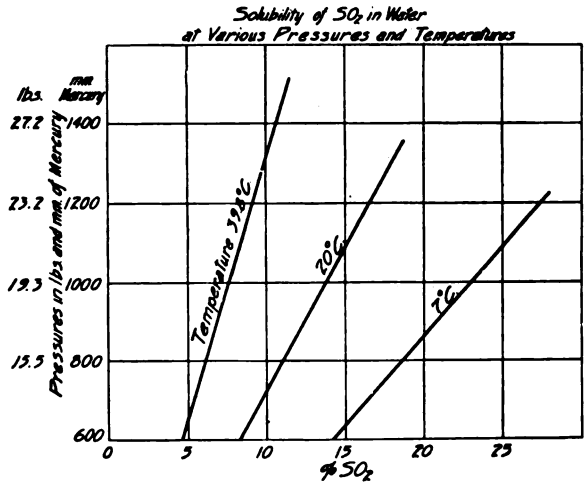

FIG. 9.

equivalents in pounds per square inch. Thus, the pressure per square inch exerted by a column of mercury 1200 mm. (= 1.2 m.) high is $39.37 \times 1.2 \times .49111 = 23.2$ pounds, since a cubic inch of mercury weighs .49111 pounds.

QUESTIONS

(1) When and by whom was the sulphite process invented, and why is it called by this name?

(2) What led to the use of lime in the cooking liquor, and what was the result?

(3) (*a*) What takes place when sulphur burns? (*b*) If properly operated, what is the composition of the burner gas?

(4) Explain the effect of too much and of too little air.

(5) What is the function of the combustion chamber?

(6) Describe one type of gas cooler and explain its purpose.

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ABSORPTION OF THE SULPHUR DIOXIDE

39. Absorption Systems.—The next step in the process of acid making is the absorption of the cooled sulphur dioxide gas in water in the presence of calcium and magnesium compounds, with which it forms calcium bisulphite $Ca(HSO_3)_2$ and magnesium bisulphite $Mg(HSO_3)_2$.

There have been many systems of absorption in use in the mills, but today only two processes are distinguished: (*a*) The **milk-of-lime systems,** in which the gases are brought in contact with a suspension of hydrated lime $Ca(OH)_2$ in water (milk of lime), and (*b*) The **Tower systems,** in which the gases are introduced at the bottom of towers that have been charged with limestone or dolomite, over which, water runs from a tank at the top of the tower.

Both systems have been in use since the earliest days of the sulphite process, and a great number of modifications of the original systems have been in operation in the various mills. Only the most usual types will here be considered.

MILK-OF-LIME SYSTEMS

40. Preparation of the Milk of Lime.—Burnt lime containing a high percentage of magnesia is slaked by mixing it with warm water in an iron tank equipped with a stirring device. The lime and magnesia combine with the water, forming hydrates of lime and magnesia, according to the equations,

$$CaO + H_2O = Ca(OH)_2$$

$$MgO + H_2O = Mg(OH)_2$$

The hydrated lime, calcium hydrate, which is very slightly soluble in water, is screened into a wooden tank equipped with an agitator, to keep the lime in suspension, and sufficient water is added to give the milk of lime a strength of 1°Be.; the solution is then ready to be used in the absorption system.

41. The Tank System.—A three-tank system is shown in diagram in Fig. 10. It consists of three wooden tanks, arranged one above the other, so that the milk-of-lime solution can flow from one tank into the next below. When the tanks are filled, the gas from the coolers enters at the bottom of the lowest tank *A*, in which it is absorbed by the milk of lime, forming at first

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calcium (and magnesium) monosulphite $CaSO_3$ (and $MgSO_3$) which is very sightly soluble, but which, in the presence of an excess of sulphur dioxide, combines with the sulphur dioxide, forming the soluble calcium bisulphite $Ca(HSO_3)_2$ (and magnesium bisulphite $Mg(HSO_3)_2$). The reactions are:

$$Ca(OH)_2 + SO_2 = CaSO_3 + H_2O$$

$$CaSO_3 + SO_2 + H_2O = Ca(HSO_3)_2$$

The gas from the burner enters the lowest tank *A* through a lead pipe *a*. The unabsorbed gas leaves the first tank *A* through a lead pipe *b*, and enters the bottom of the second tank *B*, where

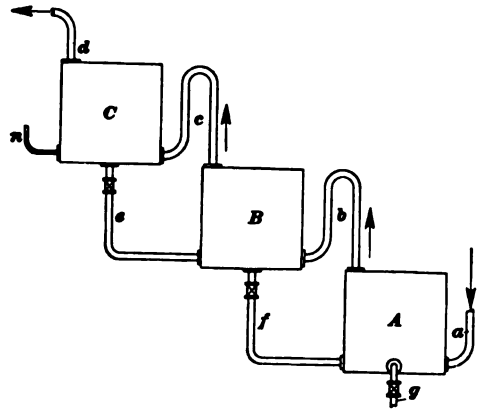

FIG. 10.

it reacts with the milk of lime, as in the tank *A*. The gas that is not absorbed in tank *B* enters the third tank *C* through the pipe *c*, the unabsorbed gas (nitrogen and oxygen) leaving this uppermost tank through *d*. The gas is either pulled through the system by means of a vacuum or is forced through the tanks under pressure. In the vacuum system, it is difficult to discover leakage; and air may enter and cause the formation of SO_3, which forms insoluble sulphate with the lime and causes trouble in form of deposits in the bottom of the tanks (which again means a loss of sulphur and lime), and plugs pipes and valves. The pressure system is better, and small leaks are easily discovered.

42. In the intermittent system, the gas is passed through the system until a sample taken from the lowest tank shows the desired strength. This tank is then emptied through *g*, and the

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weak liquor in tank *B* is allowed to flow into tank *A*, through pipe *f*, the still weaker liquor in tank *C* is run into tank *B* through *e*, and tank *C* is again filled with fresh milk of lime through *n*. Gauge glasses are placed on each tank, to permit control of the height of the liquor.

In the more modern installations of this type, the process is made continuous by regulating a continuous flow of liquor from one tank to the other, so as to obtain a permanent flow of acid of the proper strength from the lower tank *A*.

The individual tanks in this system may in some cases be equipped with agitators and may also be divided into horizontal compartments, having openings arranged in such a way as to obstruct the passage of the gas, in order to secure a better contact of gas and liquor.

The diagram explains in principle a great number of milk-of-lime systems. All these tank systems are now gradually disappearing in favor of more modern equipment.

43. Barker System.—Of the modern milk-of-lime systems, the best known and most widely used is illustrated in Fig. 11, which shows the construction of this equipment in detail. It consists actually of a four-tank milk-of-lime system, with an absorption tower, all combined in one steel shell, which is protected by an acid-proof lining. The lime water is fed through the pipe *A* into the upper compartment *M*, from which it flows continuously through an overflow pipe of hard lead *B* into the next compartment, *N*, emptying in the same way into the third and fourth compartments *P* and *R*. These compartments are formed by partitions of perforated copper plates *C*, through which the gas from the tower passes. The tower forms the lower half of the steel cylinder, and is separated from the upper part by means of a solid partition *D*. A pipe *E* through the center of this partition connects the lower compartment with the tower below, and the valve *F* can be so operated as to adjust the strength of acid flowing to the tower, by controlling the rate of flow of the liquid in proportion to the gas supply.

The acid entering the tower flows on a distributing plate *G*, and from this it travels over the tower filling *T*, of acid-proof stoneware, to expose a large liquid surface, absorbing the strong gas that enters at the bottom of the tower through pipe *H*. The gas that is not absorbed in the tower passes through the pipe *I* into the bottom of the lower compartment and through

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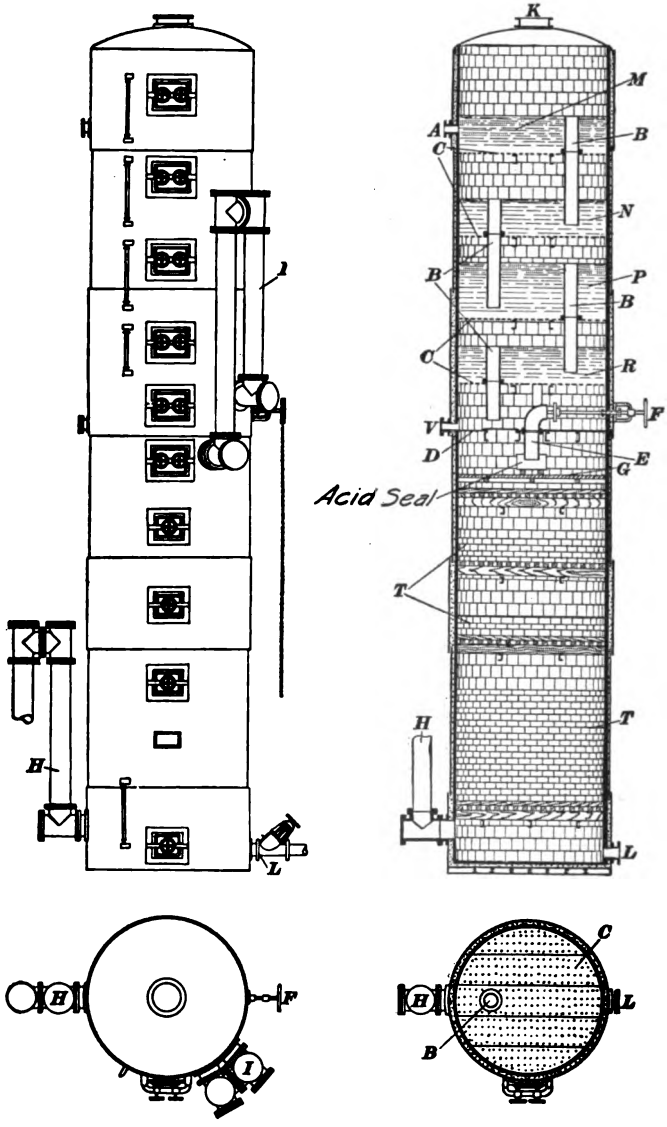

FIG. 11.

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the perforated partitions and the acid thereon, the unabsorbed gases (nitrogen and oxygen) leaving at the top of the uppermost compartment at *K*.

The perforations in the partitions are very small, in order to assure small bubbles, thus securing a large total surface of the gas and, therefore, efficient absorption; and the flow of gas is so regulated as to prevent the acid from passing through the perforations. The gas is either pulled through the system, under a vacuum equal to about nine inches of mercury, or it is forced through, under a pressure of about 4½ pounds per square inch.

The finished acid leaves at the bottom of the tower through a pipe *L*. Sludge from impurities in the lime are flushed out at *V*.

In starting up this system, lime water is allowed to run into the tower in a quantity sufficient to cover all the plates and seal the bottom of pipe *B*. The gas is pulled through the system until the acid has reached the desired strength, whereupon, the lime-water line *A* is opened a little, and the flow is gradually increased, until acid of proper and uniform quality and in desired quantity is obtained.

44. The capacity of this system is regulated by the amount of lime water admitted; and since there must be a certain relation between the lime water and the gas, the number or size of the perforations in the partitions must be regulated to meet these requirements.

The combined SO_2 is regulated by the strength of the lime water. If the water gets very warm in the summer months, it is difficult to keep the combined SO_2 low, because it is necessary to add sufficient lime to keep up the total SO_2 of the acid. In such cases, it happens quite frequently that a soft precipitate is formed on the top plate, and this has to be removed from time to time. Another difficulty that may be experienced with this system is the clogging up of the perforations of the lower partition with sulphate of lime, due to inefficient operation of the sulphur burner.

45. Milk-of-lime System, with Wedge Pyrites Furnace.— In Fig. 12 is shown a layout of an acid plant, operating a Wedge pyrites furnace in connection with the milk-of-lime absorption system. Here *A* is a conveyor, *B* is a hopper for storage, *C* is the feed hopper, *D* is the furnace, *E* is a dust chamber, *F* is a gas pipe, and *H* is a scrubber.

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The gases pass, as will be seen in the diagram, first through a dust chamber *E*, where most of the heavy solid particles are retained; while the fine dust, as well as sulphur trioxide gas, are removed by washing with a water spray, as the gases pass through the scrubber *H*. In contact with the water, the gases are cooled to some extent, but are further cooled in the cooler *I* before they enter the absorption tower *J*. The diagram also

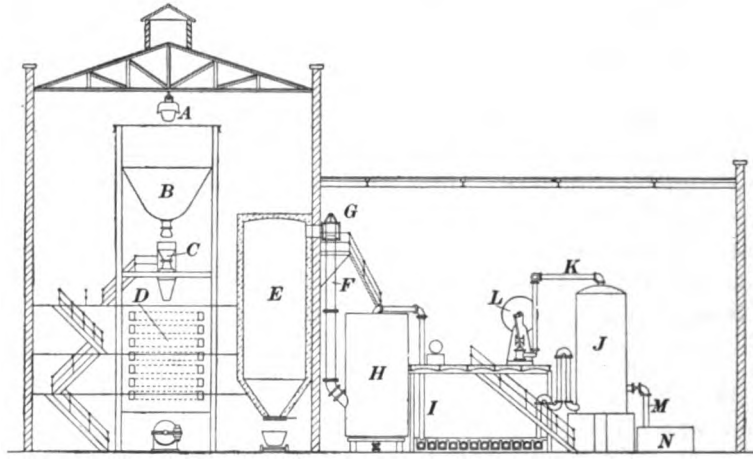

FIG. 12.

shows the vacuum pump *L*, connected by pipe *K*, and the discharge pipe *M* for delivering the acid into the acid-storage tank *N*; but the diagram does not include the recovery process.

46. The composition of the acid obtained with this system, and with the milk-of-lime systems in general, is slightly different from that obtained with the tower system, because of the fact that the lime used in this process generally contains considerably more magnesia than the limestone employed in the tower system. The main reason for using a high-magnesia lime is that magnesium monosulphite ($MgSO_3$) as well as magnesium sulphate, which are formed during the process, are more soluble than the corresponding calcium compounds, which would settle out and cause inconveniences in clogging the openings of the perforated plates and also in the pipe lines.

Some manufacturers favor the milk-of-lime system on account of the high magnesia content of the acid, which they consider beneficial in the cooking process.

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TOWER SYSTEMS

47. Mitscherlich Towers.—This absorption process, which has been used for many years almost exclusively in the European sulphite mills, has, during the last few years, gained much ground on this continent at the expense of the milk-of-lime systems, which were more generally in use here. It was mentioned that many varieties of milk-of-lime systems have been developed and introduced in the mills, and the same is true of the tower systems, although to a more limited extent.

The essential difference between the two systems is that in one of them, the base is added in the form of milk of lime, while in the other, the tower system, lime-stone is used. The acid towers are often called **Mitscherlich towers,** because they were used by Mitscherlich in his first attempts at producing sulphite pulp commercially. In the first installations, Mitscherlich made use of one single tower, consisting of a circular wooden shaft 3 to 5 feet in diameter and 100 to 135 feet high. Near the bottom of the shaft was a heavy wooden grate, supporting the limestone, which filled practically the entire tower, which was open at the top. Above the tower, was a tank from which water was continually running into the tower and forming a thin film on the surface of the limestone. The gas from the burners passed through two vertical pipes, connected with a header at the top, and reaching to about two-thirds or three-fourths of the height of the tower itself. The pipes served as a cooler, and the cooled gas entered the tower at the bottom beneath the grate. The gas, consisting of sulphur dioxide, nitrogen, and excess oxygen, passed through the tower, the sulphur dioxide being absorbed by the water; the resulting solution reacted with the limestone to form calcium monosulphite $CaSO_3$, a salt which is practically insoluble in water, but which combines with an excess of sulphur dioxide to form calcium bisulphite $Ca(HSO_3)_2$, which is soluble in water. The chemical reaction taking place in the tower may be expressed as follows;

$$2SO_2 + H_2O + CaCO_3 = Ca(HSO_3)_2 + CO_2$$

In addition to the sulphur dioxide that is combined with the calcium, the acid leaving at the bottom of the tower always contains a certain amount of free sulphur dioxide, so that the formula of the acid may be expressed as $Ca(HSO_3)_2 + SO_2$ (in H_2O). The carbon dioxide gas CO_2 that is formed in the

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reaction leaves at the top of the tower, together with the nitrogen and air.

48. The natural draft obtained in the original one-tower system was secured by the difference in specific gravity of the gas in the two cooler pipes and in the tower, due to the difference in temperature and the difference in composition of the gas. In later installations, the tower was not entirely open at the top, but the unabsorbed gases escaped through a pipe in which a steam jet was placed to aid the draft.

With the natural draft, weather conditions played an important part, and it was soon realized that the absorption system could be much more uniformly operated with artificial draft, produced by pressure or vacuum pumps or fans. Artificial draft was absolutely necessary if several towers were used in series, in place of one single tower.

49. Other Tower Systems.—Kellner used a six-tower system, and Ellis made use of four shorter towers. When several towers are employed, all towers are closed at the top with the exception of the last tower, which allows the unabsorbed gases to escape through a pipe at the top. With these systems, the sulphur dioxide is not all absorbed in the first tower; the gases are therefore conducted through lead pipes from the top of the first tower to the bottom of the second tower, and so on through the whole system. The water descending through the last tower absorbs the remaining sulphur dioxide, forming a weak liquor, which is pumped from the bottom of this tower to the top of the previous tower. In this way, the acid is gradually strengthened during its journey from one tower to the other, while the gas moving in the opposite direction is gradually weakened and, finally, exhausted.

50. With the one-tower system, it was suggested to divide the tower into several compartments by means of grates. This would relieve the full weight of the stones from the bottom grate; it would also permit the filling of the individual compartments, and would simplify inspection at the different heights. Another advantage claimed was that the compartments could be charged with stone of varying composition, of varying magnesia content, in order to regulate the composition of the acid by regulating the solubility at different heights.

In modern tower construction this idea is abandoned. The

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towers have only one grate, and the charging with limestone takes place from the top only. In order to prevent binding of the limestone, the towers are given a slightly conical form; *i.e.*, they are frustums of cones, with large ends down. Another feature of modern tower construction is that it is mostly made from concrete, rather than from pitch-pine. The walls of the concrete towers are heavily reinforced and are lined with acid-resisting salt-glazed tiles, laid in a mixture of litharge, cement, and glycerine. The height and diameter, and also the number of towers, depend upon the desired capacity, as well as upon the quality of the limestone.

51. A Recent Two-tower System.—Recently, a two-tower system has been introduced in a number of mills, of which Fig. 13 (*a*) shows a plan and 13 (*b*) an elevation of a layout that includes rotary sulphur burners *A*, combustion chamber *B*, cast-iron pipe *C* connecting the combustion chamber with cooler *D*, which consists of lead pipes, partly submerged in water, partly sprayed with water. The heavy lead fan *E* driven by motor *F* draws the gas through the cooling system and forces it through a lead pipe *G* into the bottom of one of the concrete towers *H* at *N*. The grate *O* is usually 16 to 20 feet above the gas inlet. The space between the grate and the gas inlet is filled with wooden checkerwork, which permits of an intimate mixture of gas and strong acid, which descends through the tower and leaves at *U*. The unabsorbed gas passes through the grate, and is gradually absorbed by the acid trickling down, strengthening the acid solution and dissolving the limestone that is loosely piled above the grate *O*. Between 75% and 95% of the SO_2 from the burner is absorbed in this tower, which is called the **strong tower.** The unabsorbed gas leaving the top of this tower is conducted through a tile pipe *J* to the bottom of the second tower, now the **weak-acid tower,** which in construction is identical with the first tower. Water is sprayed from the top of the weak-acid tower, absorbing on its way the weak SO_2 gas, forming sulphurous acid H_2SO_3, which acts upon the limestone and forms a weak solution of bisulphite; this is pumped from the bottom of this tower to the top of the strong-acid tower through pipe *P*, and is distributed by plate *Q*. The operation of the towers is made reversible by means of cocks and gas seals *I*; in which case, the weak-acid tower becomes the strong-acid tower, and *vice versa*. On account of the good absorption of

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the gas in the strong tower, the gas entering the second tower is so weak that this tower can be charged with limestone during the operation. The gas fan *E* is directly connected to a variable

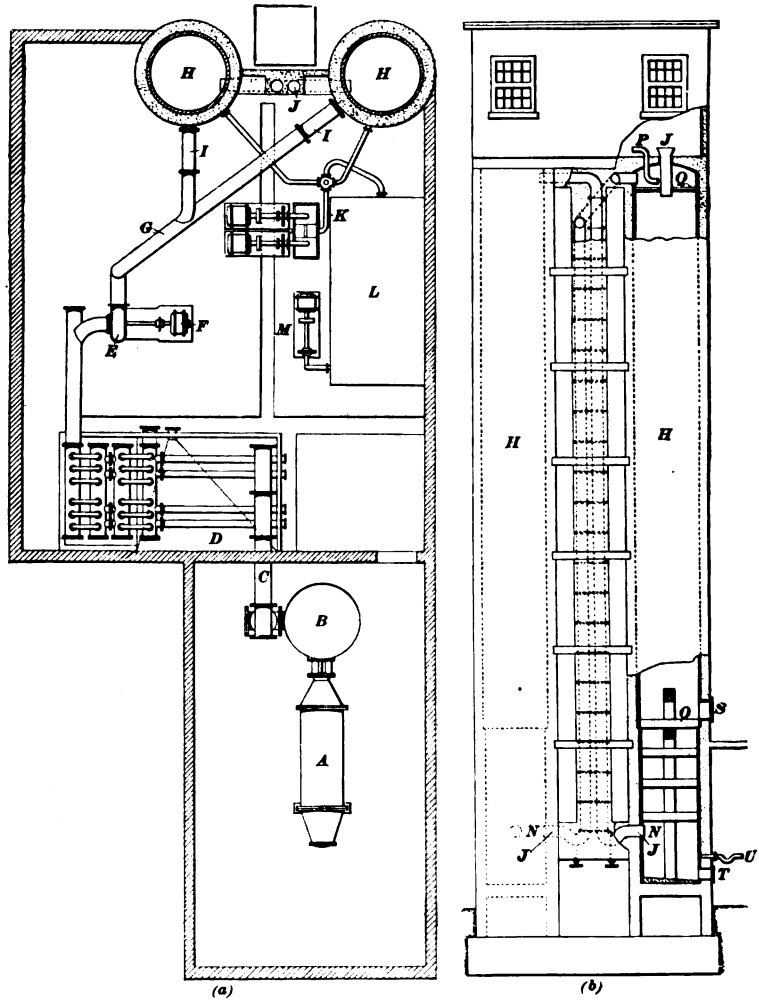

FIG. 13.

speed motor *F*, allowing a variation in the volume of gas and, thereby, a variation of the capacity of the system. Before the tower acid from the strong tower is pumped to the recovery tower, which will be described later, it passes through a settling

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tank *L*, in which any sand and other impurities are settled out. Cleanouts are provided at *S* and *T*.

52. The total SO_2 of the acid leaving the strong tower may be regulated to any desired strength by adjusting the gas and the water. The **combined** SO_2, by which is meant the SO_2 combined with the calcium (and magnesium), may be regulated by changing the temperature of the water, since the reaction on the stone is more rapid at higher temperature. The temperature of the water used in acid making is a very important factor in the production of uniform acid. Due to the high temperature of the water in some localities in the summer time, it is difficult to maintain a strong acid and a low percentage of combined SO_2. In order to secure uniformity throughout the entire year, some mills are cooling their water for acid making in a refrigerating system, with very satisfactory results.

53. In the three-tower system, which is operated in the same manner as the two-tower system, one tower is always *down* for washing and filling. All three towers are interchangeable. In the four-tower system, three towers are always in operation, the fourth being down for washing and filling. In this system, two towers are used as strong-acid towers and one as a weak-acid tower.

While the two-tower system is generally adopted at the present time, four towers are recommended in certain instances.

54. Grade of Limestone to Use.—An all-calcium limestone or a limestone with 8 to 10 per cent magnesium carbonate will work without any difficulty in the two-tower system. If, however, the available limestone is very high in magnesia, such as in dolomite, a different construction is required. Magnesium carbonate is less soluble in the acid than calcium carbonate; and while the latter is dissolved, the magnesium compound will be suspended in the acid for some time before it entirely dissolves. It is necessary in this case to raise the grate to about 40 feet above the gas inlet and to run more slowly. This decreases the capacity of the tower, and four towers are recommended in such cases.

55. Regulating Strength of Acid.—The composition of the strong-tower acid, that is, the per cent of total sulphur dioxide and combined SO_2, is regulated according to the requirements of the mill, and depends upon the type of recovery system used. But, while it may be possible to produce a raw acid containing

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as much as 4.5% total SO_2, of which 3.3% is free SO_2, it is customary in many mills to keep the raw acid at a strength of 2.8% to 3.0% total SO_2 and 0.9% to 1.2% combined SO_2, depending upon the recovery system to bring the total SO_2 up to the requirements of the digester acid.

When the tower system is started up, the acid is circulated within the towers until the acid has reached a certain strength. The gas is at first very weak, since it takes some time to bring the sulphur burner up to capacity. During this time, the fan is running at low speed. When the acid in the towers is sufficiently strong, the towers are connected up to the reclaiming tower.

The regulation of the strength of the acid was already mentioned above. It is at times difficult to keep the combined SO_2 low in the summer time, when the water is warm, without making changes in the construction of the towers, unless a less soluble stone is available for such cases.

COMPARISON OF THE TWO ACID-MAKING SYSTEMS

56. Generally, it can undoubtedly be said that the tower system is more flexible and is simpler to operate than the milk-of-lime systems. There is a certain amount of heat developed in both systems due to the chemical reactions, which results in an increase in temperature of the acid, and this increase is about 8°C.—but greater with the milk-of-lime system than with the tower system. Less power is required in the tower system, and it is also claimed that it takes less labor to operate this system than the milk-of-lime system. There is a difference in the finished acid, due to the fact that a lime with a high magnesia content is advantageous in the milk-of-lime system, which is, therefore, generally employed; while in the tower system, a limestone with low magnesia content is preferable, although not necessary, for a satisfactory operation. As a consequence, the acid made by the milk-of-lime system, as a general rule, has a much higher magnesia content, and some advantages have been claimed for this acid in the cooking process The magnesium salts are more soluble than the correspond ng calcium salts, and do therefore not so easily form a precipitate of monosulphite. Magnesium bisulphite does not decompose so easily, and there is therefore a more gradual liberation of the SO_2 in the cooking

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process when an acid with high magnesia content is used. This permits, it is claimed, a higher temperature in the process, which is necessary in quick cooking. There is no doubt but that the pulp resulting from cooking with high-magnesia liquor has a more pliable fiber than that resulting from pure calcium bisulphite liquor.

RECOVERY OF SULPHUR DIOXIDE

57. An Explanation.—In order to explain the final step in acid making, the strengthening of the acid to the point desired for the cooking process, it is necessary to refer briefly to the cooking process itself. When the digester charge, consisting of chips and strong acid, is heated, the pressure increases very rapidly, due to the presence of the liberated gas; and in order to be able to reach the temperatures required for complete cooking of the wood without passing a certain maximum pressure, gas as well as liquor must be allowed to escape from the top of the digester during part of the cooking time. This gas and liquor is *recovered*, or *reclaimed*, as completely as possible, and is used in the acid-making to strengthen the tower acid, or, as it is termed, to *build up* the cooking acid.

There are various methods of reclaiming the acid, a few of which will be mentioned here. The strong acid relieved at the early stages of the cooking process may be cooled and conducted to the bottom of the acid storage tanks, or it may be added to the liquor running into the strong-acid tower, or it may be pumped to the top of the so-called recovery tower together with the raw acid from the strong acid tower.

58. Recovery Tower.—The **recovery tower,** which was introduced by Thorne, is a wooden or concrete tower, similar to the acid towers, but filled with checker work of hard wood or tile. The gases from the digesters, after being cooled, enter the bottom of this tower, while the raw acid, at times mixed with relief liquor, enters the top of the tower. The acid absorbs gas and is strengthened, so that it leaves the bottom of the recovery tower with a strength of about 5.5% to 6.5% total SO_2. Gas that is not absorbed in this tower leaves the top of the tower, and is conducted through a lead pipe to the acid plant, where it is mixed with the burner gas entering the strong-acid tower.

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59. A Milk-of-lime Reclaiming System.—In Fig. 14 is shown a reclaiming method used in connection with a milk-of-lime system. Gas and liquor from the digester *A*, after being cooled in the cooler *B*, are conducted to the bottom of the acid storage tank *C*, where the gas is partly absorbed. The unabsorbed gas leaves the top of the acid-storage tank and passes into the bottom of a reclaiming absorption tower *D*, in which it is absorbed by the acid coming from the acid system and entering at the top of the reclaiming tower. Any unabsorbed gas leaves the top of this tower and is mixed with the burner gas.

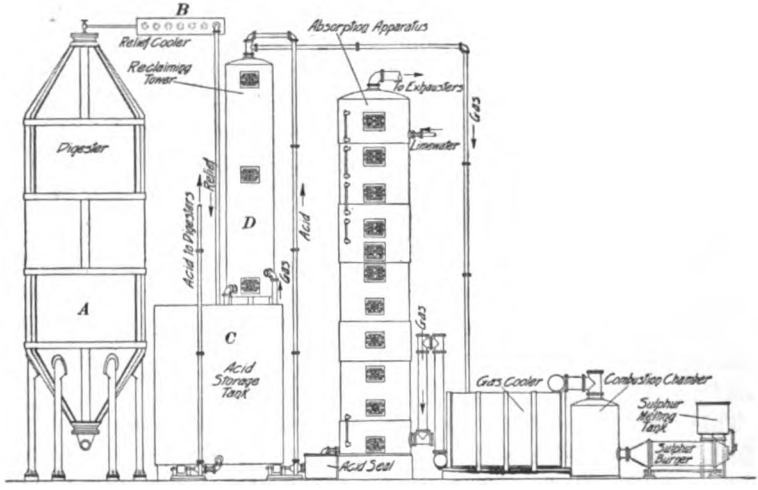

FIG. 14.

60. A Patented Reclaiming System.—In the patented reclaiming process shown in Fig. 15 in connection with the tower acid system, the liquor and gas from digester *A* pass through a separator *B*; here the gas is separated from the liquor, which is cooled at *C* and stored at *D*, and the almost pure gas is cooled at *H* and enters the bottom of the recovery tower *K*. The weak liquor leaving the tank *D* passes a cooler *E*, and is mixed at *F* with the weak acid, as this is being pumped to the strong-acid tower. The acid from the strong-acid tower *L* is pumped to the top of the recovery tower *K*, where it absorbs the relief gas, bringing the strength of the cooking acid as it leaves the tower up to above 5.5% total SO_2. Since no base (lime or magnesia) is added in the recovery tower, the combined SO_2 remains the same as in the tower acid.

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The rest of the equipment shown in Fig. 15 is: *M*, sulphur burner; *N*, combustion chamber; *P*, gas cooler; *R*, gas fan; *T*, weak-acid tower (becoming strong-acid tower when gas is switched from *L*); *V*, *V*, acid pumps; *W*, acid-storage tank; *X*, water inlet; and *Y*, gas vent. The two acid towers are identical and interchangeable. Burner gas entering *L* is about 15% SO_2, relief gas entering at *K* is about 98% SO_2 and is at about 35°C.; relief liquor in *D* is about 1% SO_2; the strong acid entering *K* is at about 20°C., and contains about 1% combined SO_2 and

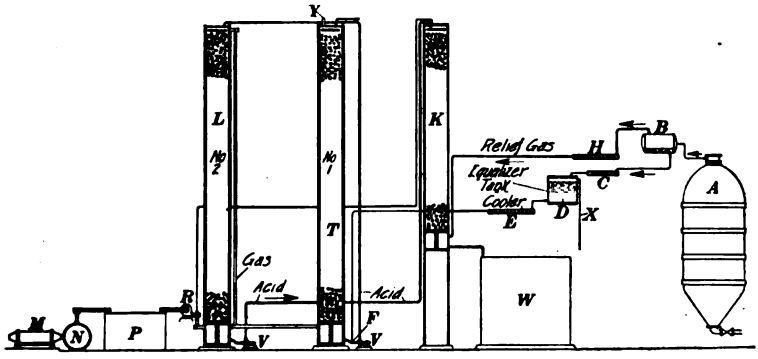

FIG. 15.

about 1.6% – 2.6% free SO_2; fortified acid at *W* contains about 1% combined SO_2 and 3.5% – 4.5% free SO_2, a total of 4.5% – 5.5% SO_2.

61. Acid Storage Tanks.—The cooking acid is kept in a number of large, closed storage tanks, each of a capacity of 50,000 gallons or more, and are usually made from 6-inch, long-leaf yellow pine, heartwood (free from sapwood). Each tank has a manhole in the top, and the individual tanks are connected with each other by lead pipes. Recently such tanks have been successfully constructed in reinforced concrete, with acid resistant tile lining.

For the maintenance of a uniform acid, it is important to have a large storage capacity and good circulation in the tank system. Where a number of tanks are used, it is customary to introduce the acid from the reclaiming tower at the bottom of one of the tanks, and this tank is connected with another tank by means of an overflow at the top. The overflows of the other tanks are partly at the top and partly at a lower point. The

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tanks with high overflow represent a permanent large volume of acid; the acid is not directly drawn from these tanks when a digester is filled, and they assist as an equalizer in maintaining a uniform acid. These tanks also have, of course, connections near the bottom, so that they can be drawn from in emergency cases. The total acid-storage capacity should not be less than 18 hours requirement.

The tanks should be equipped with test cocks for control of the acid, and also with gauges indicating the volume of the acid.

CONTROL OF ACID-MAKING

62. General Conditions.—A constantly uniform acid of good quality is only obtainable with proper regulation of the burning process, adjustment of temperature, and quantity of gas and water, and with general control by means of recording and indicating instruments and chemical analyses. Some of the methods in use will now be considered.

63. Temperature of Gases before Cooling.—A recording pyrometer is commonly used for ascertaining temperatures of gases before cooling. The principle upon which this instrument operates is based on the well known fact that when two dissimilar alloys are joined (making a thermo-couple) and heated at the point of junction, an electric current is generated. This is called the **thermo-electric principle,** and a milli-voltmeter measuring instrument is employed to interpret the units of electricity in terms of degrees of temperature. It is possible to use this type of pyrometer wherever it is desired to indicate or record temperatures up to 3000°F., for practically any commercial requirement. This instrument should be supplied with an automatic, internal, cold-end compensator; its function is to compensate automatically for any variation in temperature at the cold end of the thermo-couple.

The fire end of the thermo-couple is preferably placed in the combustion chamber; but, due to the heat and corrosive action of the gas, it should be protected by a nipple. For temperatures up to 800°F., a nipple made of cast iron, about 2 inches in diameter, and with a hole drilled in the center that is large enough to admit the fire end, serves very well. If, however, the temperature of the gas is in excess of 800°F., the cast iron will last

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only a comparatively short time, and some other composition must be used, such as fused silica or quartz. Nipples made from this material, however, are objectionable, because of being extremely fragile. In many instances, the fire end is located in the hot gas main, between the combustion chamber and lead cooler; here the gas will have cooled sufficiently to permit the use of the cast-iron protective nipple. The fire end and the pyrometer instrument (voltmeter) are connected together by a flexible extension, thus permitting the instrument to be conveniently located where it may be observed by the operator, to guide him in his work.

The frictionless, smoke-chart, recording system is employed with this recording pyrometer. This is desirable, because there is then no retarding action to the pen arm due to friction. A sensitized smoke-surface chart is used, against which the pen arm is periodically pressed every 10 seconds. The pen arm then swings clear of the chart and is left free to take a new position, leaving a white dot impression each time. The record produced is therefore a series of white dots making a practically continuous line. The mechanism is essentially the same as the ordinary recording meter. When the chart is put in place on the recording instrument, the smoked surface is sensitive. When the record is completed, the chart is removed and dipped into a fixative solution, to fix the record. The line is always visible, the effect of the fixative being simply to make the record and semi-transparent smoked surface permanent, so that it will not rub off.

64. Sublimation.—A simple test for sublimation of sulphur is to bring a cold glass rod in contact with the hot gases. If the SO_2 gas contains sulphur vapors, these will be cooled down and will deposit as a yellow layer on the glass rod. To correct this, more air must be admitted.

65. Testing of SO_2 Gas after Cooling.—*Temperature* is measured by means of an indicating or recording thermometer placed in the gas line.

The *vacuum* before the fan is measured by means of a U tube made of glass tubing and placed in the gas line. It is filled about one-half full of water, and the difference in the levels in the two arms measures the vacuum in inches of water. The vacuum is usually $\frac{3}{4}$ to $1\frac{1}{2}$ inches.

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STRENGTH OF GAS

66. Orsat Apparatus.—In most mills, the percentage of SO_2 in the gas mixture is determined by means of an **Orsat apparatus,** Fig. 16. This consists of one or more absorption pipettes *A*,—see also detail sketch, Fig. 16 (*b*),—a gas burette *B*, graduated from zero to 100 c.c. and enclosed in a water jacket. The upper

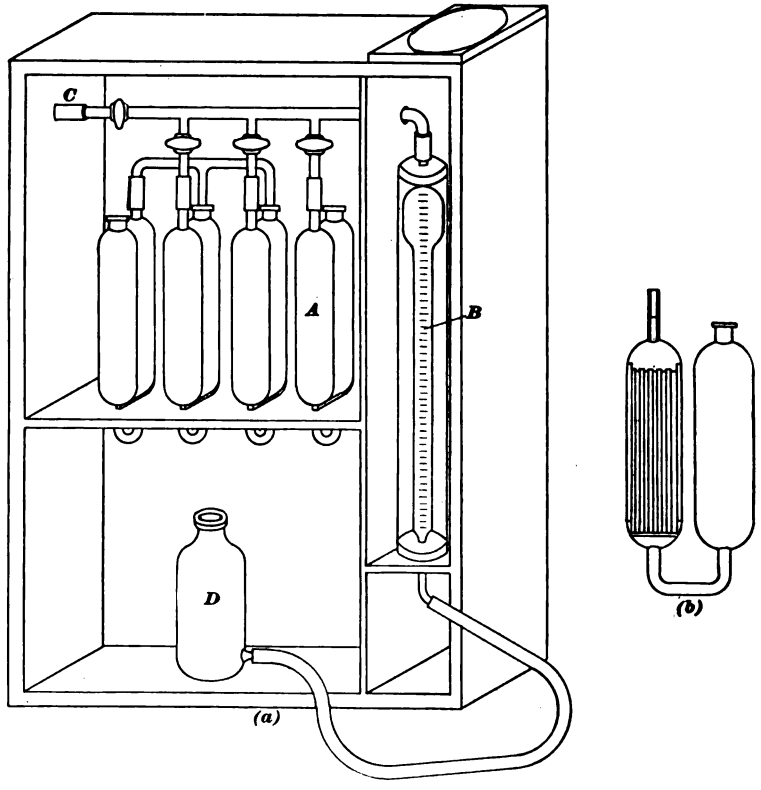

FIG. 16.

part of the burette is connected by means of a capillary tube to the absorption pipettes and to the gas line at *C*. The lower end of the burette is connected by means of a rubber tube to a leveling bottle *D* containing water, or, still better, mercury. The absorption pipettes contain a strong solution of potassium hydrate KOH.

When a test is made, the gas burette is filled with water by lifting the leveling bottle *D*; the apparatus is then connected up to

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the gas line at *C*, and by lowering the water bottle, gas is drawn into the burette. By means of the three way cock *C*, the gas is allowed to escape into the air, by lifting the leveling bottle and thus pressing out the gas. This is repeated a couple of times in order to secure a good sample. Finally the burette is filled with gas by adjusting the water levels in bottle and burette at zero point at atmospheric pressure. By opening the cock leading to the absorption pipette and moving the leveling bottle up and down several times, the gas is pressed into the absorption pipette, where, finally, all the SO_2 is absorbed by the potassium hydrate, which is spread in a thin film over the filling of glass tubes. The decrease in gas volume, representing the volume of SO_2 absorbed, is determined by reading the water level in the burette at atmospheric pressure.

67. Mono SO_2 Recorder.—A very good apparatus for recording automatically the percentage of sulphur dioxide in the burner gas is the so-called **Mono SO_2 recorder,** shown in Fig. 17. Either water or compressed air may be used as motive power, depending on local conditions.

The absorption apparatus is mounted in the lower part of the cast-iron case, to which it is fastened by means of three screws. The pressure medium by which the apparatus is driven passes through the regulating valve *A* and the chamber *B* into bottle *C*, which contains mercury. The mercury is thus forced up in tubes *D*, *E*, *F*, and *G*. Tube *D* connects with the burette *H*, in which the volume of gas is ascertained, tube *E* is in communication with the outside air, and the upper part of tube *F* passes into an expansion of tube *G*.

The lower part of tube *F* passes into the bottom of chamber *B*, and is thus only indirectly connected with the mercury in bottle *C*. The position of this inner chamber *B* in bottle *C* is such that the mercury in tube *F* will always rise higher than that in tube *E* or *G*. As the pressure is increased, the mercury is finally forced out of the chamber *B*, through tube *F*, and runs down into tube *G*. When all the mercury is thus discharged, the pressure is released through contact with the atmosphere, and the excess pressure in bottle *C* disappears. The mercury in the communicating tubes *D* and *E* then also recedes and again gradually fills up the bottle *C* completely; part of the mercury runs into chamber *B*, which is provided with openings at the top for this purpose. In this way, the lower outlet of tube *F* in the chamber

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B is sealed again, there is no more connection with the atmosphere, pressure builds up again in bottle *C*, and the cycle above described repeats itself. In this manner, an alternately rising and falling movement of the mercury is brought about, which movement is employed in the following manner:

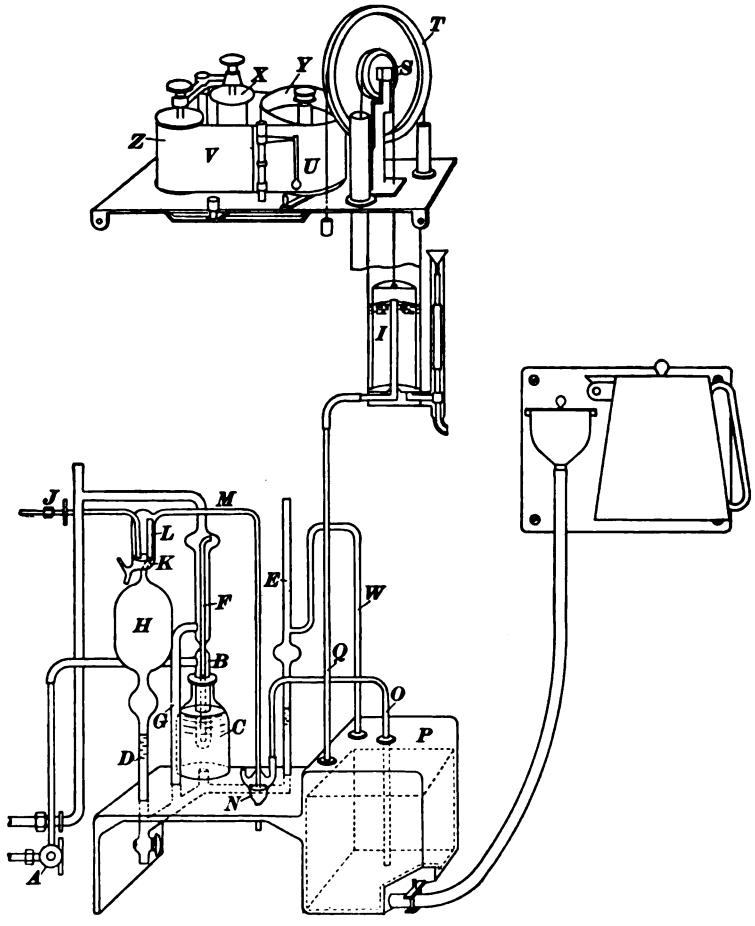

Fig. 17.

When the mercury falls as above described, the gas to be analyzed is drawn in from its source to the absorption apparatus. Through the coupling *J*, the mercury seal *K*, and tube *L*, the gas then passes into the burette *H*, where it is measured. When the mercury rises, the gas from the burette *H* is forced through

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tube *M*, mercury seal *N*, and tube *O*, into the caustic potash container *P*, which is filled with the absorption liquid. The sulphur dioxide is here absorbed, any remaining gas being forced through tube *Q* into the gasometer *I*, which is suspended in a glycerine solution, where it is measured again, and the difference is recorded as follows: When the gas enters, the gasometer rises and turns the pulley *S*, which in turn finally acts on pulley *T*. On the latter, and connected with it by means of a metal chain, hangs the pen *U*, which draws the analysis curve on the chart *V*. When the pen has come to a stop on the chart, the mark indicated represents the gas absorbed, expressed as a per cent. When gas is drawn into the burette, tube *W* allows communication with the atmosphere, the gasometer then falls back to its original position. Thus the apparatus is ready for a new analysis. The chart is drawn from roller *X* over the drum *Y* by means of a 36-hour clock within the latter, and is automatically rolled up on roller *Z*, or it may be cut off at will.

The motive power should be supplied to the instrument at a constant pressure; then by adjusting the regulating valve *A* the desired number of analyses in a given time can be obtained. About ten tests per hour are sufficient to meet all requirements. Periodically, say about three times weekly, the sample line which supplies gas to the instrument should be removed from the gas header for about one-half hour. This will permit the admission of air and the recorder should register zero; if it does not, proper adjustment of the pen can be made by means provided.

68. Testing for leaks is accomplished in the following manner: when the mercury begins to fall in the burette, tightly close the end of the sample tube, thus creating a partial vacuum. If no leaks are present, the mercury will cease to fall; if the mercury continues falling, a leak in the apparatus or line is present, and it must be corrected before the instrument is put in operation, otherwise inaccurate analyses will result.

69. The absorption liquid is prepared by dissolving 1 pound of potassium hydrate in 1 (U. S.) gallon of water. This solution is placed in the absorption chamber, and will last several days, depending on the strength of the gas and the number of analyses made. As the absorption liquid approaches the exhaustion point, if allowed to remain in the instrument, a gradual drop in strength of the gas will be noted and inaccurate results will be

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recorded. The spent liquid, therefore, should be removed and replaced by a new solution just before this point is reached.

70. Determination of Sulphur Trioxide SO_3 in the Gas.—For routine tests, **Reich's apparatus** is ordinarily used. The principle is shown in Fig. 18, in which *A* is a bottle of about 200 c.c. capacity, with a stopper and two glass tubes, *L* and *M*. The stopper has a third hole, which can be closed by means of a glass rod *N*. Tube *L* is connected to a rubber tube *D* with a pinch cock *F*, and has a stopper *G*, for connection with the gas line. Bottle *B* has a capacity of about 1 liter, and is equipped with a stopper through which pass the two glass tubes *H* and *K*; *H* is connected to *M* by rubber tubing, while *K* ends in a rubber tube that extends below bottle *B*, and has a pinch cock *E*. A graduated cylinder *C* completes the apparatus.

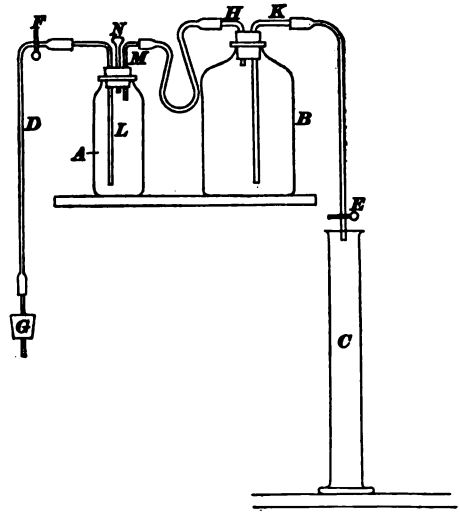

FIG. 18.

The analysis is made as follows: Bottle *A* is charged with 50 c.c. of distilled water, a few cubic centimeters of sodium bicarbonate solution, starch solution, and a little iodine solution, just enough of the last to give the contents of the bottle a deep blue color. Bottle *B* is filled with water, both bottles are closed with stoppers as shown, and the apparatus is connected up to the gas line by means of stopper *G*. When the apparatus is absolutely tight, that is, when no water flows into cylinder *C* when pinch cock *F* is closed and *E* is open, but full of water, gas is allowed to enter bottle *A* slowly, by opening both pinch cocks, until the blue color in *A* disappears. Pinch cock *E* is then immediately closed, and 10 c.c. of decinormal iodine solution is added to the contents in *A* by removing stopper *N*. This being done, glass stopper *N* is again put in its place, thus closing the bottle, and a little water is allowed to pass through *E*, until the gas just reaches the lower end of tube *L*. All water in the

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graduated cylinder C is then discharged, and gas is drawn slowly through the solution in A, by opening cock E and allowing water to run into C. Bottle A is shaken during this operation, in order to secure a perfect absorption of the gas; and as soon as the color of the solution in A disappears, pinch cock E is closed, and the volume of water in C is measured. Care must be taken not to pass the *end point.*

From this measurement, the percentage of SO_2 in the gas is calculated as follows: The reaction between sulphur dioxide and iodine solution is expressed in the following equation

$$2I + 2H_2O + SO_2 = H_2SO_4 + 2HI$$

The 10 c.c. of $\frac{N}{10}$ iodine solution reacts with .03204 g. SO_2, and since 1000 c.c. of SO_2 weighs 2.9266 g. at 0°C. and 760 mm. pressure, this 0.03204 g. of SO_2 corresponds to $\frac{1000 \times .03204}{2.9266}$ = 10.95 c.c. SO_2.

If the volume of water in C were 70 c.c., the total gas drawn through the solution would be 70 + 10.95 = 80.95 c.c.; and the percentage of SO_2, accordingly, would be $\frac{10.95}{80.95} \times 100 = 13.53\%$.

For convenience the following table showing relation between volume of water and per cent SO_2 by Reich's method, using 10 c.c. $\frac{N}{10}$ iodine solution, may be used.

Volume of water c.c.	Per cent SO_2 by volume	Volume of water c.c.	Per cent SO_2 by volume
208.1	5.0	84.3	11.5
188.2	5.5	80.3	12.0
171.6	6.0	76.7	12.5
157.6	6.5	73.3	13.0
145.5	7.0	70.2	13.5
135.1	7.5	67.3	14.0
126.0	8.0	64.6	14.5
117.9	8.5	62.1	15.0
110.8	9.0	59.7	15.5
104.4	9.5	57.5	16.0
98.6	10.0	55.4	16.5
93.4	10.5	53.5	17.0
88.6	11.0	51.6	17.5

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71. After finding the per cent SO_2 from the table or from the curve, Fig. 19, using the volume of water employed to draw gas through the iodine solution, repeat with sodium hydrate NaOH solution, and from the same table or from the curve, find the total acid. The difference is the per cent SO_3 in the burner gas; and this figure divided by the total acid, expressed as SO_2, is the per cent of SO_3 in the SO_2·SO_3 mixture.

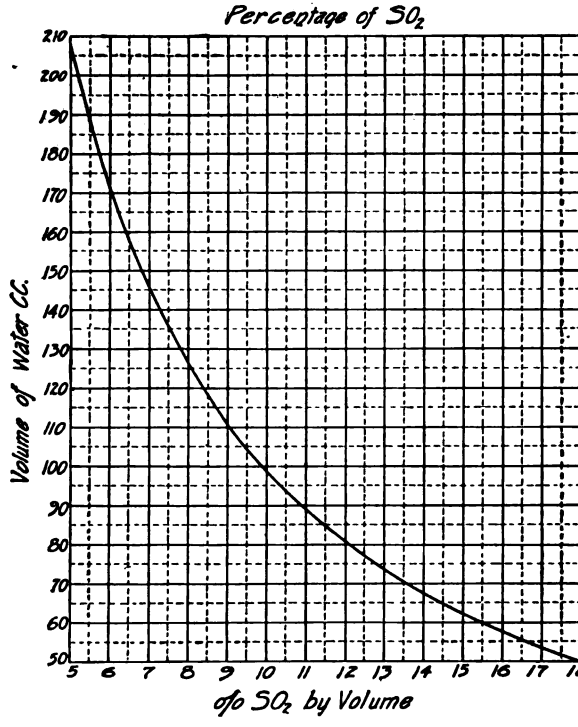

FIG. 19.

If the volume of water in the latter determination was 67.3 c.c., the percentage of total acid as SO_2 was 14.0 (see table), and therefore the SO_3 content was 14.0 − 13.53 (previously found) = 0.47%, or, based upon the total absorbed gas, $\frac{.47}{14} \times 100 =$ 3.36% SO_3.

72. Richter's Method.—While this apparatus can be used for the determination of SO_3, it is customary to determine the SO_2 with the Orsat apparatus; and for an exact determination of the SO_2 content of Richter's method is recommended. According

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to this method, the gas is passed, at a rate of 1000 c.c. in 20 to 25 minutes, first through a hard-glass sampling tube, surrounded with an iron jacket, and then through a tube 30 cm. long, which is filled with garnets and bits of porcelain and is cooled with ice. The gas is measured by the amount of water delivered by the siphon bottle that is used to induce its flow. After passing 2 to 5 liters of gas, the tube is washed out by drawing pure air through it, and, finally, is washed into a beaker, with water, to remove the SO_3 which has condensed on the beads. This is then determined gravimetrically by precipitation as $BaSO_4$.

73. SO_2 in Unabsorbed Gases.—It is advisable to test from time to time the gases leaving the top of the weak-acid tower, to make sure that no unabsorbed SO_2 is leaving the system. This is preferably done with Reich's apparatus, as described above.

Influence of SO_2- and CaO- Content on Specific Gravity of Solutions

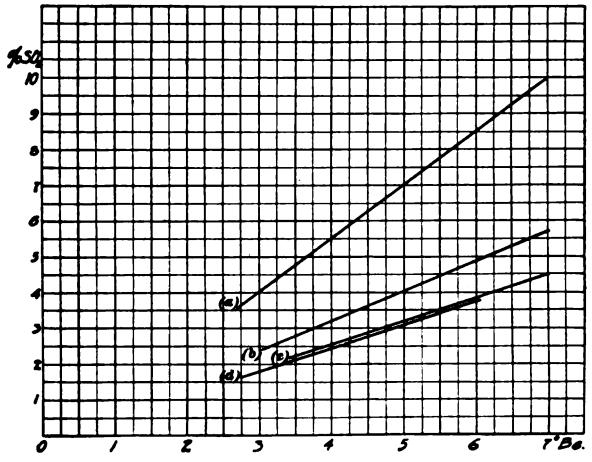

FIG. 20.

(*a*) Solution of SO_2 in water (Scott)
(*b*) Acid from tank system with 74% free SO_2 (DB)
(*c*) Acid from tower system with 62% free SO_2 (Harpf)
(*d*) Acid from tank system with 61% free SO_2 (Harpf)

74. Testing of Acid.—The acid maker is often provided with a hydrometer for a superficial test of the raw acid from the strong tower. This test may be useful in mills where there are no great variations in the raw acid; but it must be remembered that the density of the acid is influenced both by the total SO_2 content and by the percentage combined with the lime. The

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preceding chart, Fig. 20, shows the variations in degrees Baumé with varying relation of free SO_2 to total SO_2; the table gives the Baumé reading for various strengths of acid, with almost constant relation between free and total SO_2.

The actual composition of the raw acid as well as of the cooking acid is obtainable only from chemical tests. The methods in use are as follows;

RELATION BETWEEN LIME AND BAUMÉ READING (AT ORDINARY ROOM TEMPERATURE)

°Bé.	Per cent SO_2			Per cent lime	Relation total SO_2 / lime	Relation free SO_2 / total SO_2
	Total	Free	Combined			
3.9	2.59	1.84	0.75	0.66	3.9	0.71
4.0	2.63	1.77	0.86	0.75	3.5	0.67
4.1	2.75	1.86	0.89	0.78	3.5	0.68
4.2	2.56	1.76	0.80	0.70	3.6	0.69
4.3	2.91	1.88	1.03	0.90	3.2	0.65
4.4	3.10	2.02	1.08	0.95	3.3	0.65
4.5	2.98	1.97	1.01	0.88	3.4	0.66
4.6	3.08	2.03	1.05	0.92	3.3	0.66
4.7	3.04	1.99	1.05	0.92	3.3	0.66
4.8	3.09	1.99	1.10	0.96	3.2	0.65
4.9	3.13	2.01	1.12	0.98	3.2	0.64
5.0	3.27	2.07	1.20	1.05	3.1	0.63
5.2	3.53	2.27	1.26	1.10	3.2	0.64
5.3	3.49	2.21	1.28	1.12	3.1	0.63
5.4	3.62	2.29	1.33	1.17	3.1	0.63
5.5	3.66	2.37	1.29	1.13	3.2	0.65
5.6	3.83	2.37	1.46	1.28	3.1	0.62
5.7	3.87	2.44	1.43	1.25	3.1	0.63
5.8	3.78	2.34	1.44	1.26	3.0	9.62
6.0	3.94	2.43	1.51	1.32	3.0	0.62

TOTAL SO_2.—One cubic centimeter of the acid, measured with a pipette, is diluted with about 100 c.c. of distilled water, and is titrated with $\frac{N}{10}$ iodine solution in the presence of starch solution. The number of cubic centimeter of $\frac{N}{10}$ iodine solution required multiplied by .3204 gives the total SO_2 in the liquor, expressed as a per cent.

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FREE SO_2.—A separate sample of the acid is titrated with $\frac{N}{10}$ sodium hydrate solution, using phenolphthalein as indicator. If 1 c.c. of acid is used, the number of cubic centimeters of hydrate solution is multiplied by .3204, giving the percentage of free SO_2.

COMBINED SO_2.—Subtract the free SO_2 from the total SO_2.

LIME.—The value for combined SO_2 multiplied by .875 gives the per cent of lime, if a pure calcium stone or lime was used in the acid making. Calcium as well as magnesium may, of course, be determined directly and more accurately by the usual gravimetric methods.

75. Crandon Acid-Control System.—An instrument known as the **Crandon acid-control system** is constructed for automatic control of the free SO_2 in the raw acid. This instrument works very satisfactorily in connection with the milk-of-lime system, and it is also used in some mills operating the tower sysnem The instrument based upon the relation between the conductivity and the strength of acid. The principle involved is very simple, in that an alternating current of electricity is carried through the acid *L* by the use of electrodes, *A* and *B*, Fig. 21, the size and location of which are determined by making tests of the actual system under consideration, taking into account, of course, the speed at which the system is being operated, the strength of the acid that is being made, and also the percentage of lime that is being used.

A solenoid *C* is set in series with the electrodes *A* and *B*, and operates the instrument in the following manner: A beam is suspended over the solenoid, and has, at either end, suitable pieces of metal (contactors) *E* and *F* that dip, as the beam tilts, into mercury cups *G* and *H*, which are directly connected to the motor *M* that operate the valve *V*, set in the milk-of-lime supply line. This beam has connected to it an armature *K*, which is drawn down by the solenoid when the acid is growing stronger; it continues to pull until such time as the acid is strong enough to pull the contactor *E*, on the same end as the armature, into the mercury *G*, thus closing the starting switch of the motor, which would operate the valve toward an *opening position*, so as to admit more milk of lime; and when the liquor in the system has been sufficiently diluted, so that the current flowing through the liquor and solenoid is not sufficient to hold the armature beam

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and contactor down on that side, the counter-balancing weight *W*, on the opposite end of the beam, will carry the contactor *F* on that end down, toward or into the mercury *H*, causing the motor to stop or to operate the valve toward a *closing position.*

The instrument is regulated for a stronger or a weaker acid by moving the weight on the right-hand side of the beam to right or left according to the strength of acid desired. The sensitiveness

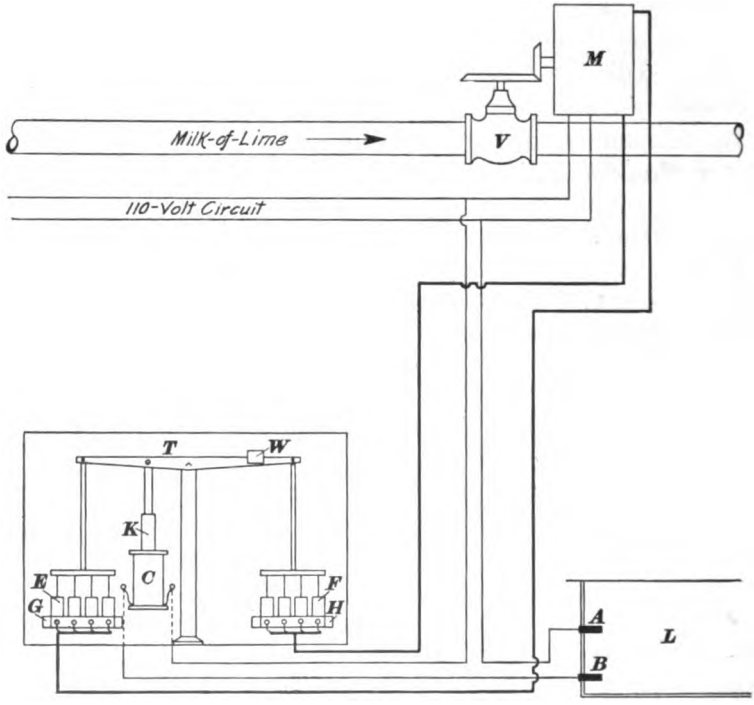

FIG. 21.

of the instrument depends a great deal upon the voltage used in the solenoid. The installations vary in voltage from 12½ to 110 volts, and, the windings on the solenoid vary, of course, according to the voltage that is being used. The circuit that comprises the electrodes and solenoid is entirely independent from the one that operates the motor; it is controlled by the mercury switches at either end of the main beam.

The motor itself is a fractional-horsepower reversing motor that runs at very high speed, around 2000 r.p.m. It is connected up

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to the valve spindle on the milk-of-lime line by means of a speed reduction device, which consists of a worm-gear reduction and a set of spur gears.

For complete control and record of the acid-making operations, indicating and recording instruments should be provided that will give the temperature of the gas as it enters the absorption system, the temperature of the water and the acid, and the volume of acid produced.

QUESTIONS

(1) Explain briefly the course of the materials in (*a*) the milk-of-lime system, and (*b*) in the tower system for absorption of sulphur dioxide.

(2) What is the advantage of using a lime high in magnesia for a milk-of-lime system?

(3) What is meant by (*a*) combined SO_2? (*b*) free SO_2?

(4) How is the recovery of sulphur dioxide accomplished?

(5) Mention some of the accessories that are helpful in the control of the operations connected with the preparation of cooking liquor.

(6) What do you consider the most important factor in maintaining the best (not necessarily the strongest) cooking liquor? Why?

(7) What chemical principles are involved in the determination of SO_2 in burner gas?

THE COOKING PROCESS

THEORY OF PROCESS

76. Composition of Wood.—The present-day routine of the cooking process is based more upon practical experience than upon actual knowledge of the chemical reactions that take place in the digester during the cooking. Our knowledge of the chemical composition of the woods is still too limited to permit of an entirely satisfactory explanation of all the various reactions in the digester. But Klason's investigations of the composition of one of the chief constituents of the wood, the so-called *lignin*, have resulted in a theory of the cooking process, by which it is possible to explain some of the most important reactions, and they form an excellent basis for future research. In order to be able to discuss Klason's theory of cooking and also the question of yield and quality of pulp, it is necessary to review briefly the composition of the wood.

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It is generally recognized that all woods are composed of cellulose, lignin, sugars and resins. But there is some difference of opinion with regard to the amount (proportion) of each of these constituents, and also as to their exact chemical constitution. Cellulose belongs to the group of organic compounds known as carbohydrates. Its chemical formula is expressed as $(C_6H_{10}O_5)_n$, n being unknown; its molecular weight is undoubtedly very high, and it is very resistant to the action of chemicals. It is on the basis of this resistance toward chemical reagents that the commercial processes for isolation of the cellulose fiber are based. Cellulose is, however, by no means absolutely resistant to hydrolysis and oxidation; and if the processes are not carefully controlled, the cellulose itself will break down chemically and physically, and will partly decompose into soluble products. This explains the variation in yield and in the quality of the fiber from different cookings.

77. The *sugars* contained in the wood belong to the same large group of organic substances as cellulose; but they are of lower molecular weight, and they are less resistant to hydrolysis. They are either, like cellulose, hexoses, or are pentoses; some of them dissolve in boiling water, while others are hydrolyzed by the dilute acid in the cooking process, and still others resist even the cooking process, and remain with the cellulose in the sulphite pulp.

78. By *resin*, or *pitch*, is usually understood the substances that can be extracted from wood by means of organic solvents, such as ether, alcohol, benzol, etc. We may consider resin to be a mixture of fat and rosin in about equal proportions; it is generally accepted that it is the fats which cause the pitch troubles in the pulp. These are only to a very limited extent dissolved in the cooking process.

79. The chemical composition of lignin is less known even than the composition of cellulose. It is hardly a uniform compound, being rather a mixture of two or more lignins of different constitution, but of similar reactions, typical for the lignin complex as a whole. This lignin complex contains unsaturated groups, and it easily forms additional products; it is easily oxidized, and it contains so-called methoxy (CH_3O) groups. In this respect it resembles coniferyl alcohol, and Klason has shown that there is a great similarity between the lignin reactions and the reactions of coniferyl alcohol. Of particular interest is the behavior of these

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two compounds toward mineral acids. Both lignin and coniferyl alcohol *resinify* when heated with a mineral acid; they form very dark, colored substances, and this undoubtedly explains why Tilghman was unable to obtain a light-colored pulp when he attempted to cook wood with a sulphurous acid solution without the addition of any base; and it also explains the "burning" of the pulp, when insufficient calcium is present to neutralize the acids formed. Klason considers the lignin a condensation product of coniferyl alcohol; and the main reaction in the cooking process consists in the addition of bisulphite to the unsaturated groups of the lignin molecule, forming soluble calcium salts of lignin sulphonic acid.

According to this theory, the lignin complex binds four molecules of sulphur dioxide, two of which are permanently combined to ethylene groups (CH=CH), one less permanently, and one molecule of SO_2 loosely combined with an active carbonyl group =CO.

Since the SO_2 is added to the lignin as bisulphite, it is natural that for each molecule of SO_2, one-half molecule of calcium will be used; and it has been suggested as a control test during the process of cooking, to determine the amount of SO_2 present as bisulphite or "half-free" SO_2. There should always be sufficient half-free SO_2 in the acid to completely dissolve the lignin of the wood. In other words, a sufficient amount of calcium must be present.

80. The average composition of bone-dry spruce wood, disregarding the fraction of a per cent of ash, is

Cellulose	53.0%
Sugars	14.0%
Lignin	29.0%
Protein	0.7%
Fats and Resins	3.3%
	100.0

On this basis, approximately 100 g. of SO_2 and 45 g. of CaO should be theoretically required per 1000 g. of bone-dry wood, for complete solution of the lignin. And these figures are very close to those obtained in commercial operation. If toward the end of the cooking process, the liquor should not contain sufficient sulphite to react with the ethylene groups (of the lignin),

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some of the sulphite, which is loosely combined (to a carbonyl group), may combine permanently with ethylene groups; in which case, it would be possible to cook with less than the theoretical requirement of bisulphite.

It is accordingly important to have sufficient lime in the acid at the beginning of the cooking process. But even with an excess of calcium at the beginning of the cooking process, a great proportion of this calcium may disappear from the active cooking liquor, due to abnormal conditions existing in the digester.

81. Effects Produced by Cooking.—If a normal cooking acid is heated, a small quantity of sulphur trioxide is always formed; in the presence of suspended sulphur, this decomposition is more rapid, especially if the sulphur is in a very fine form in the acid. .150 g. of very finely suspended sulphur (such as formed in the decomposition of thionic acids) or .250 g. of flowers of sulphur, per liter, would, according to Klason, during normal cooking time and at 135°C., decompose the cooking acid to such an extent that all calcium would be precipitated as gypsum. The effect of the presence of selenium in the cooking acid is 300 times as great as that of sulphur. Also, thiosulphuric acid ($H_2S_2O_3$) and thionic ($H_2S_2O_6$ and $H_2S_3O_6$) acids are formed when cooking acid is heated to the temperatures prevailing in the digester. The quantity of these acids increases slowly, the more slowly the more free SO_2 there is present. At a later stage these acids are decomposed into sulphur trioxide, sulphur dioxide, and free sulphur, and the reaction is taking place fairly rapidly as long as calcium is present in the liquor as bisulphite. Finally, all the calcium will precipitate as gypsum.

These are, of course, abnormal conditions, which must be guarded against; and one of the objections to the return of relief liquor to the acid system at the last stages of the cooking is based upon the danger of contaminating the fresh cooking acid with these foreign acids.

In connection with this, the danger of poor circulation must also be mentioned, since this may result in local shortage of calcium at some points in the digester; and wherever the quantity of calcium is insufficient for the neutralization of the acids formed in the process, there is the danger of the acids resinifying the undissolved lignin, as mentioned above. The result is a dark coloring of the pulp or burning of the fiber.

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82. Products of the Cooking Process.—The formation of the calcium salt of the lignin-sulphonic acid is the most important reaction in the cooking process; but other reactions are also taking place, of which not a great deal is known. It is known that formic acid and acetic acid are formed, and they can be identified in the waste liquor as well as in the relief gas. Also furfurol is formed, due to the action of acid upon the pentosans of the wood; it is found in the waste liquor, but mostly in the condensate of the relief gases. This latter is a heavy liquid, which often collects at the bottom of the acid tanks.

Spruce turpentine, consisting largely of cymene, is also a by-product of the cooking process. It follows the relief gases; and if these are returned direct to the acid tanks, the turpentine, being lighter than the acid, will collect as a layer on the top of the acid, from where it may be removed by some skimming method. In other places, it is separated, together with the condensed strong SO_2, from the relief gas after cooling, and is conducted to a separate tank, where it collects on the top and can be drawn off intermittently or continuously.

It is considered very advantageous to remove this substance, which usually is obtained in largest quantities with fresh spruce wood, since an accumulation of the turpentine in the cooking acid is undesirable; partly, because it makes the cooking control difficult, and partly, because it has been made responsible for difficulties with pitch in the pulp.

With the relief gas, methyl alcohol is also removed from the digester. Approximately 14 pounds of methyl alcohol is formed per ton of pulp during the cooking process, and about one-third of this escapes with the relief gas, the quantity varying with the method of relieving. The amount of oils in the relief gas, including spruce turpentine and furfurol, is, according to some investigators, about 2 to 3 pounds per ton of pulp, depending upon the nature of the wood.

In the cooking process, the higher sugars of the wood are hydrolyzed into simple pentoses and hexoses, the latter forming the material for fermentation and production of ethyl alcohol from the waste liquor.

METHODS OF COOKING

83. Direct and Indirect Cooking Processes.—Reference was already made to the difference in the two cooking processes

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known as the Ritter-Kellner process and the Mitscherlich process. The former, which is by far the most commonly used, is called the **direct cooking process,** because the digester charge is heated by direct steam; the steam condenses in the digester and thus constantly dilutes the acid, which should consequently be added in high concentration. It is possible with this method to bring the temperature up very quickly, and thereby shorten the cooking time to 8 hours or even less. The process is therefore also often referred to as the **quick-cooking process.** The Mitscherlich process is an **indirect process,** in which the digester charge is heated by means of steam-heated copper or lead coils, placed inside the digester. The steam condenses in the coils, and no dilution of the acid takes place during the process of the cooking; consequently, the acid does not have to be so strong as in the direct cooking process. The indirect process is a **slow-cooking process,** the cooking time being from 20 to 30 hours or more. The maximum temperature during the cooking is from 125° to 135°C., while in the direct, quick-cooking process, the temperature is usually around 140° to 145°C. and may go up to 155° and 160°C.

In other respects the two processes are identical, and the construction of the cooking vessels is practically the same, except for the modification required for the difference in method of heating.

DIRECT, OR RITTER-KELLNER, PROCESS

84. Cooking Vessels.—One of the great difficulties in the development of the sulphite cooking process has been the construction of the cooking vessels and, especially, the development of a suitable lining, one that will resist the action of the sulphur dioxide solution and gas. Tilghman, as well as Ekman, used lead-lined digesters and indirect heating, and the lead lining was fairly satisfactory with the small Ekman digesters of about 700 pounds capacity. With large digesters, however, the difficulties due to the difference in expansion of the lead lining and the steel shell proved very serious, epecially since lead does not, upon cooling, go back to its original size. The lining would form wrinkles, loosen from the shell, and "crawl" toward the lower part of the digester.

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85. Lining Materials.—Another lining that was used in several mills was the Salomon-Brüngger lining. It was observed that the heating coils in the Mitscherlich digesters, after a few cookings, became covered with a very resistant crust consisting of calcium deposits from the acid. The analysis of such deposits showed a calcium sulphate content of about 85%, besides sulphites of calcium and copper, oxides of iron and aluminum, and silica. This experience was utilized by Salomon and Brüngger, in forming a similar protective coating on the inside of the digester shell. The digester itself was usually of the horizontal and rotating type with a double shell. The digester was filled with acid having a high calcium content; steam admitted to the shell, whereby the acid was heated, and the SO_2 leaving the acid would cause the precipitation of monosulphite on the heated surface. The lining gradually increased in thickness, and was oxidized to sulphate in contact with the air. But while the acid-resisting quality of this lining was quite satisfactory at that time, the lining would at times break off; and with the strong acid employed on this continent, it was difficult to obtain a satisfactory crust.

Bronze has been tried for small digesters; but, at the present time, acid-resisting bronze is only used for digester fittings, where an acid-resisting metal is required.

The first brick linings were intended as a protection for the lead lining; but the lead lining is now omitted, and a modern digester lining consists of acid-resisting brick laid in an acid-resisting mortar.

86. The Digester.—The digester itself consists of a steel shell, constructed by riveting together steel plates, of about $1\frac{1}{8}$ inch thickness, by means of double butt straps. The tendency has been to increase the capacity of the digesters; and the usual size today is from 12 to 15 or 18 tons, while digesters as large as 35 tons capacity have been built.

The following table shows various dimensions and capacities of the standard digester type for direct cooking.

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CAPACITY OF STANDARD SULPHITE DIGESTERS WITH STANDARD LININGS

Size of digester		Thickness of lining, inches	Contents, cubic feet	Capacity contents, tons fiber	Gallons of acid	Cords of wood
Diameter, feet	Height, feet					
8	24	8	610	1.33	3,000	2.48
8	30	8	840	1.75	3,787	3.24
10	28	8	1,319	2.66	6,000	4.96
10	30	8	1,397	2.90	6,525	5.34
10	37	8	1,850	3.85	8,663	7.16
10	40	8	2,024	4.50	9,450	7.81
11	30	8	1,672	3.48	7,330	6.47
11	37	8	2,896	4.60	10,125	8.37
11	40	8	2,416	5.00	11,250	9.30
11	42	8	2,563	5.33	12,000	9.92
11	45	8	2,784	5.75	12,937	10.69
12	30	9	2,015	4.13	9,292	7.67
12	35	9	2,457	5.10	11,470	9.48
12	40	9	2,879	6.00	13,500	11.16
12	45	9	3,272	6.80	15,300	11.64
12	48	9	3,572	7.40	16,650	13.76
14	38	9	3,819	7.90	17,775	14.64
14	42	9	4,320	9.00	20,250	16.74
14	45	9	4,678	9.75	21,934	18.13
14	47	9	4,924	10.50	22,950	18.97
14	48	9	5,046	10.64	23,625	19.53
14	50	9	5,392	11.20	25,000	20.83
15	40	10	4,682	9.75	21,934	18.13
15	42	10	4,964	10.33	23,250	19.22
15	45	10	5,388	11.20	25,200	20.83
15	47	10	5,671	11.80	26,550	21.31
15	50	10	6,096	12.40	27,900	22.06
15	54	10	6,652	13.75	30,937	25.57
16	45	10	6,146	12.80	28,800	24.80
16	48	10	6,680	13.75	30,937	25.57
16	50	10	6,952	14.40	32,400	26.78
16	54	10	7,598	15.80	35,550	29.38
16	60	10	8,565	17.80	40,050	33.10
16	64	10	9,210	19.00	42,750	35.34
17	56	10	9,074	18.80	42,300	34.96
17	60	10	9,814	20.25	45,900	37.94
17	64	10	10,552	21.80	49,050	40.44
17	70	10	11,660	23.00	51,750	42.78

The figures in the above table are for average operation; they will necessarily vary, in respect to the last three columns, with local conditions. Digesters also vary from the dimensions given, but capacities can be approximated by comparing cubic contents.

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87. Description of a Modern Digester.—A modern digester is seen in Fig. 22, which also shows a few details regarding the lining and the top and bottom fittings. With the present method of emptying the digester charge under pressure, the conical bottom is given an angle of about 70°, and it ends in a flange, which carries the bottom bronze fitting, to which are connected flanges for the steam line, acid and drain line, and blow-off valve.

The steel shell is protected by an acid-resisting brick lining; and all fittings projecting through the lining are made of acid-resistant bronze or of hard lead. Before the digester is lined, it is exposed to high temperature and pressure several times, and the inside of the shell is thoroughly cleaned by means of wire brushes, for the removal of oil and grease. It is then covered with a coat *a*, Fig. 22, 1½ to 2 inches thick, consisting of cement and crushed quartz (1 part cement, ½ part fire clay and ½ part quartz), mixed with a 4°Be. solution of silicate of soda and water. Against this

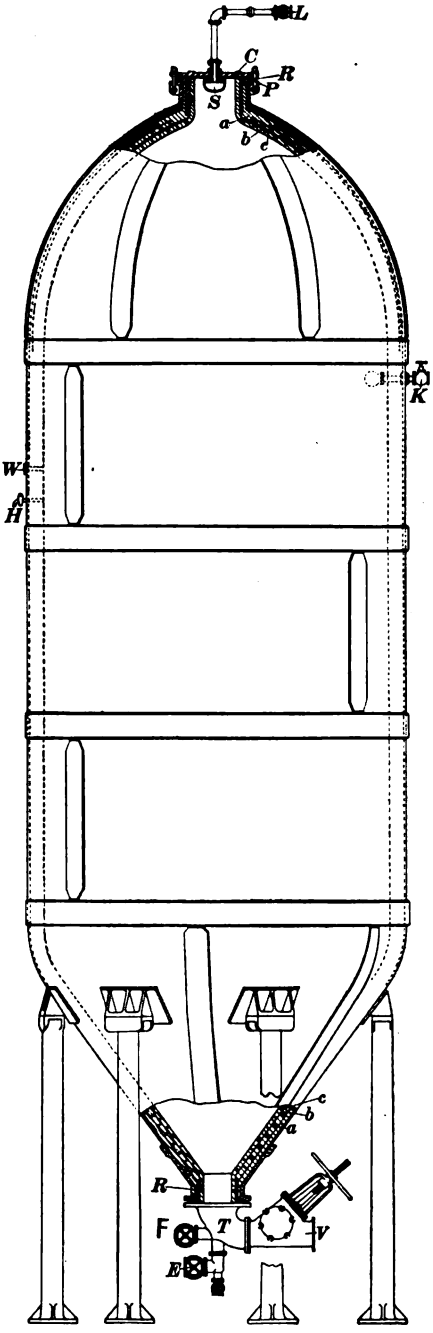

Fig. 22.

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backing is laid two courses of brick, *b* and *c*, in a mixture of cement and quartz and silicate of soda. The inner course *c* must be of carefully selected, acid-resisting brick, with a resistant joint-stock consisting of 1 part litharge, 1 part cement, ½ part quartz and glycerine, with a small proportion of silicate of soda.

The difficulties with the linings are often due to poor brick. The burning of the brick is an important feature, and it is therefore imperative that every brick be carefully inspected before it is placed in the digester. Special shapes are required for cones, corners, necks, etc.

It is also customary to lay only a certain number of bricks in one shift, and to allow these to set before the work is continued. And it is likewise the practice to place the inside course of bricks first (in a mixture of litharge, cement, and glycerine, with a little silicate), and then press the outer course of bricks in place, between the inside course and the shell, in a cement grout. At times, only one course of brick is applied, which is then laid against a heavier backing of cement. Acid-resisting bronze

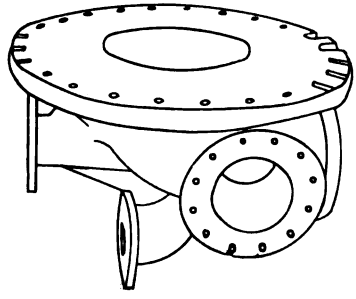

FIG. 23.

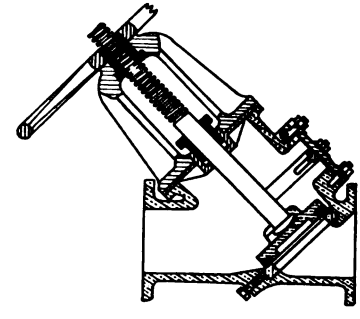

FIG. 24.

rings or sleeves prevent the acid from entering between the lining and the shell at the top and bottom flanges. The arrangement is shown at *R* in Fig. 22. For the protection of the cover, an acid-resisting bronze plate *P* is fastened to the bottom side of the cast-steel cover *C*.

88. The bronze casting T for the bottom of the digester is shown in Fig. 23. A typical blow-off valve *V* is shown in section in Fig. 24. This valve has a door through which the valve seat can be inspected and the packing properly placed before each cooking.

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In Fig. 25 a typical Y valve as used for the steam line, is shown.

89. The following composition has been recommended for a good acid-resisting bronze:

Copper	84½–85 %
Tin	9½–10½ %
Lead	4½– 5½ %
Phosphorus not less than	0.05 %
Impurities not above	0.5 %

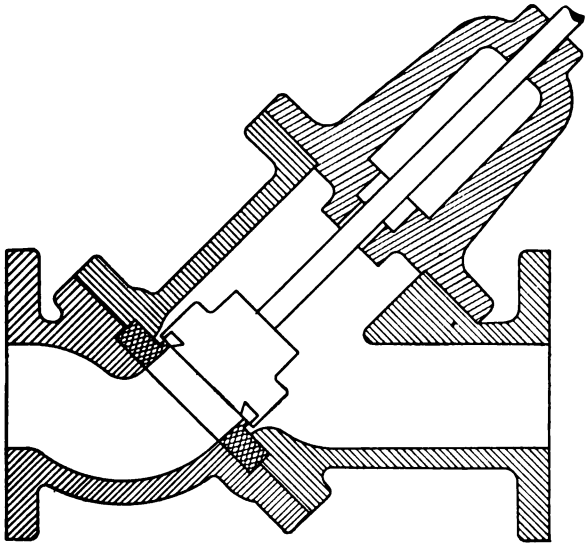

FIG. 25.

90. Thermometer wells *W*, Fig. 22, for indicating or recording thermometers, are placed either at the top or, better, one-third down the side, of the digester. They are made of bronze covered with lead.

91. The digester also carries fittings for connection with the acid and gas relief line *L* at the top of the digester. Usually, this is placed on the cover; but, in order to avoid the trouble of disconnecting the relief line when the cover is removed after each cooking, this line is frequently connected up to the side of the digester neck. At any rate, the outlet should be covered with a good-sized strainer *S*, of acid-resisting bronze or, better, of hard lead, to keep chips and fiber from entering the relief line. These

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strainers have a large number of $\frac{1}{8}''$ or $\frac{1}{16}''$ perforations, and may have the form of a ball or a cone. Or a perforated plate may be placed in the neck, resting upon a bronze ring projecting from the lining.

Steam, as a rule, is admitted only at the bottom fitting of the digester; but in a number of installations, several steam inlets are provided for on the conical bottom part. The steam line is equipped with a check valve, to keep the digester contents from entering the line, in case the pressure should fall in this main, and the regulation of the steam should be done from the charging floor.

92. Some mills have their digesters equipped with a side-relief line *K*, connected up to the side of the digester, approximately 6 feet from the top. By opening the side-relief valve at a certain stage in the cooking process, acid may be drawn off, whereby a gas space is created in the upper part of the digester; this allows "dry gas" to escape through the top relief line, which permits a better gas recovery and a better circulation in the digester. The opening for the side relief is, of course, also protected by a strainer. Furthermore, the digester is equipped with recording and indicating pressure gauges and with a sampling cock *H*, for drawing samples of liquor during the process of cooking.

93. Thermometer Bulbs.—The thermometer-bulbs of both the indicating and the recording thermometers should be placed low enough on the digester to insure that they will always be immersed in the cooking liquor; and since it is desirable to locate the recorder on the top of charging floor, where it may be conveniently observed by the operator, it will be seen that a fairly long connecting tube must be used. It is therefore necessary to employ an actuating medium that will not be influenced by the changing temperatures of the atmosphere along the connecting tube. Experience has proved that a thermometer depending upon the vapor tension of a volatile liquid is best suited for this purpose. The bulb should be long enough to extend through the shell and lining and at least 6 inches into the digester; therefore, the sensitive portion of the bulb should be not longer than the 6 inches that is exposed to the cooking liquor. The bulb must always be protected from the cooking liquor by a sleeve or nipple.

94. Temperature and Pressure Charts.—For recording gauges and thermometers, a 12-inch chart is preferable to the smaller

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ones, because of its larger graduations. Due to the importance of the temperature in the cooking process, it is imperative that the recorder register accurately; therefore, it should be calibrated at very frequent intervals. This can be accomplished by immersing the sensitive portion of the bulb in an oil or water bath, and holding it at constant temperature for about fifteen minutes; the recorder should show the same temperature as an accurate indicating thermometer placed in the bath. The pressure gauges—both indicating and recording gauges should be provided—are also placed at a distance of about one-fourth to one-third from the top of the digester, the recorder being located on the charging floor.

QUESTIONS

(1) What are the principal constituents of wood, and in what proportion (approximately) are they present?

(2) Why is it necessary to have sufficient lime everywhere in the digester?

(3) (*a*) What is the effect of selenium in the digester? (*b*) in the burning of the sulphur?

(4) (*a*) How is spruce turpentine collected? (*b*) why is it advantageous to collect it?

(5) Why is bronze used for digester fittings?

(6) Mention the advantages of using recording instruments in the digester house.

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95. Pressure Regulator.—In Fig. 26 is shown a pressure regulator, by means of which, steam is automatically shut off when the maximum cooking pressure is reached. The regulator is connected to the digester pressure-gauge line by means of pipe *A*, which enters the regulator underneath the diaphragm *B*. As soon as the pressure in the digester exceeds a predetermined maximum pressure, which is regulated by weights, *W*, the diaphragm forces the lever arm *C* upwards; this opens the water valve *D*, which allows water to enter through *E* and *F* into the cylinder *G*, forcing up the piston and weight *H* and causing *K* to fall, thus closing steam valve *V* on steam line. When the decreased pressure allows weight *W* to fall, the valve *D* is reversed, and the water in *G* escapes through *F* and *L*.

96. Chip Bins.—These are constructed of wood or of concrete lined with wood, and are located above the digesters, so that the

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chips can be fed into the digester by gravity. Cylindrical steel bins are also in use. In order to assure a rapid filling, a sharp angle should be provided for the inverted pyramid or cone that forms the bottom of the chip bin. When so constructed, the men do not have to enter the chip bin in order to assist in loosening the chips, which it is necessary to do, especially in cold weather and with very wet chips, when these freeze together and are difficult to move. To assist in loosening the chips at the

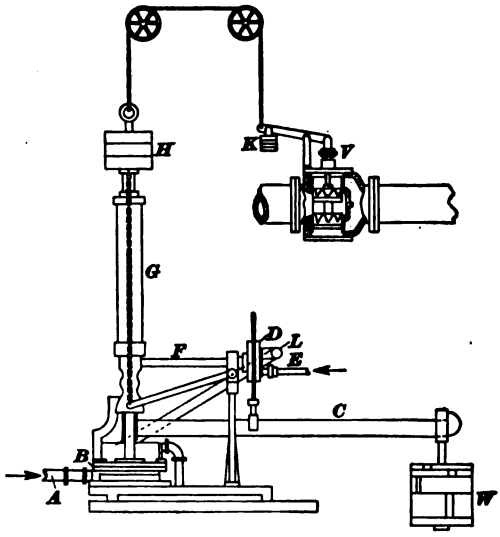

FIG. 26.

bottom of the bin, two or more steam pipes are connected up to the bin at this place. A chip bin usually has a capacity of at least two digester charges. A large mill will often have a huge common bin that runs the full length of the digester house and with a spout for each digester. Entering a chip bin is dangerous; but if it be necessary, the men should be protected by safety ropes and a helper.

ROUTINE OF THE COOKING PROCESS

97. Beginning of the Cooking Process.—When the blow-off valve and other lines have been closed, the digester is charged with chips, by opening the gate at the bottom of the chip bin and allowing the chips to run into the digester through a funnel,

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until the digester is full of chips. The acid is then pumped in, either through the opening at the top, or through a bottom connection with the acid line. If the acid is added at the top, a copper extension pipe is connected to the acid line, which runs along the digesters at the charging floor. During the time of acid pumping, the digester opening should be covered with a hood, and escaping gas should be removed through a suction pipe. For the purpose of observing the height of the acid during the pumping, an open, vertical glass pipe is connected up to the digester at the test cock by means of rubber tubing.

98. When the acid is added at the top, there is always, with strong acids, considerable smell and loss of gas at the charging floor. It must also be assumed that much gas is absorbed by the chips, thus weakening the acid in its passage through the chips. Consequently, there will be weak acid at the bottom, where the strongest acid is desired on account of the material dilution that occurs at this point, and which is due to condensation of steam in the cooking process. This is remedied by pumping the acid in at the bottom, which is the practice in many mills. A further advantage is thereby gained, in that chips and acid may be added simultaneously; this saves time, and the acid will unquestionably lift the chips from the narrow bottom and establish a volume of acid at this point, which should assist in a more even distribution of the heat; that is, it will create a better circulation in the digester. It is necessary, of course, to provide a satisfactory valve connection, to keep the acid from draining off when the digester is under pressure. Chips and acid having been added, the top cover is bolted on (using a gasket cut from a lap of pulp), the steam valve is opened, and the digester is gradually brought to the desired temperature and pressure. Once or twice, before the digester is brought up to full pressure, the top relief valve is opened and air is allowed to escape.

99. The points just mentioned are shown by the drops at *A* and *B* in the chart, Fig. 27, which shows the variations in pressure during the operation of a digester that is making easy-bleaching pulp. The corresponding temperature curve is shown in Fig. 28. These charts, together with Figs. 29 and 30, are about one-fourth the actual size, which is 11¼ inches in diameter. It is by following the line on the recording gauges

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and comparing the curve with a standard that has given good results under similar conditions that the cook (digester man) is able to duplicate results previously obtained. The curve also gives warning if things begin to go wrong.

The pressure, consisting of the steam pressure (which is known for each temperature) and the gas pressure (which depends upon the amount of gas present) increases very rapidly, and the maxi-

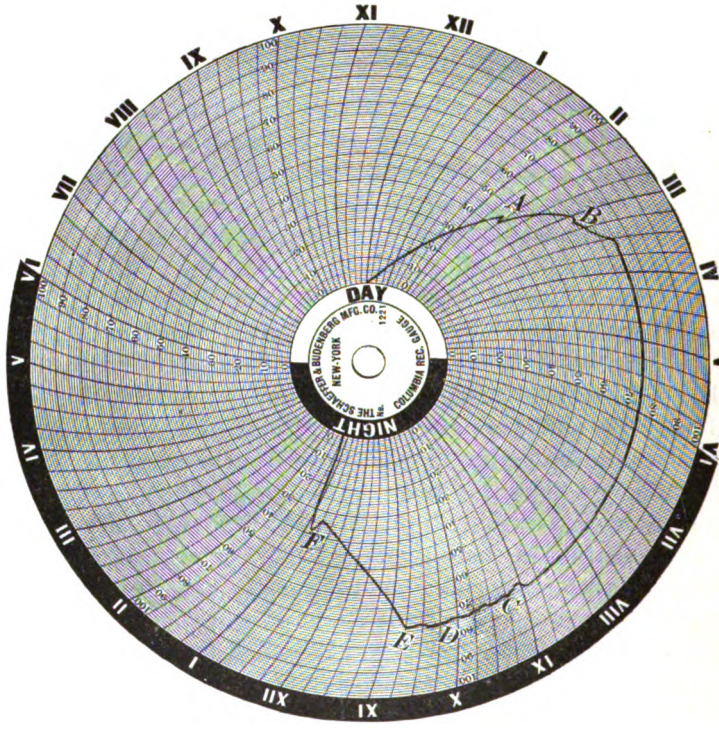

Fig. 27.

mum pressure of 70 to 80 pounds is reached within 2 to 3 hours, depending upon the method of cooking. In order, therefore, to be able to increase the temperature, it is necessary to open the top relief valve, at *B*, Fig. 27. The mixture of strong acid and gas that leaves through this line at the beginning of the cooking process, is cooled and conducted to the reclaiming tower or to the acid storage tanks, according to routine of mill. A table giving pressures and the corresponding temperature will be found at the end of this volume. Figure 28 shows a temperature chart.

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100. Recovery of Sulphur Dioxide.—The practice of relieving is of course different in the different mills; it is a very important detail of the cooking operation and in the maintenance of a strong and uniform cooking acid.

The recovery of sulphur dioxide from the cooking process was first practiced by V. Drewsen, who constructed the first separator to separate the gas from the liquor in the latter stage of the

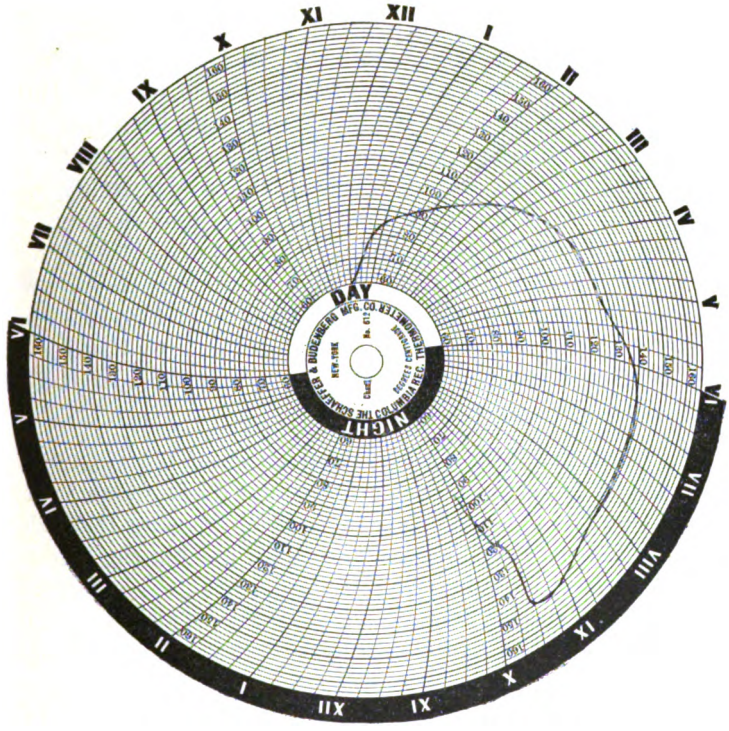

Fig. 28.

cooking process, when the liquor becomes contaminated with decomposition products. Some allow all the relief liquor up to a temperature of about 115°C. to run back to the reclaiming tower or tanks. Above this temperature, the liquor is taken through a separator, which is a large, cylindrical, steel vessel, with acid-resisting lining, about 15 feet in height by 5 feet in diameter. The liquor enters at the top through a lead pipe that extends into the separator; the separator is kept about one-third to one-half full. The pressure is here released, and most of the

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SO_2 gas will consequently leave the liquor. The gas leaving the separator passes through a cooler and enters the reclaiming system, while the weak liquor (which is drawn off at the bottom and which always contains a small quantity of SO_2) is either cooled and returned to the acid tower or it is discharged. As a rule, the weak liquor from the separator is not returned when the digester has reached a high temperature (for instance, 135°C.), as there is a danger of decomposition products, such as thionic acids and sulphur, being introduced into the fresh acid.

Horizontal pond coolers, similar to those employed in acid making, are very often used for relief gas and liquor. But, in recent years, the so-called **beehive cooler** has been introduced in many mills as being particularly suitable, on account of few flanges, thus making it easy to keep the cooler tight; and it requires less water and less space than the pond coolers. The cooler consists of lead pipe, having a diameter of 3 to 4 inches, which is wound on a conical wooden form; the cooling water is applied in a shower at the top of the cone and flows over the pipes. Separate coolers are used for gas and for liquor, when the relief liquor is separated, which is usually done at the later stages of the cooking process.

101. When the digester temperature is about 125°C. or 130°C., the side-relief valve, if such is provided, is opened at *C*, Fig. 27, and the liquor allowed to drain off, passing through the separator as described above. The liquor level in the digester is thereby lowered so much that no liquor, but only "dry gas," leaves through the top-relief valve at *D*, Fig. 27; it is accordingly possible to relieve much gas during the last stages of the cooking process, and this assists in building up a strong acid in this reclaiming tower. It is also necessary to have a gas space in the digester at the end of the process, in order to be able to reduce the pressure quickly before blowing. The circulation is undoubtedly also better, and the distribution of temperature is therefore more uniform, with the gas space created by side relief or by draining for a short period through the bottom valve, a practice which is also followed at times.

102. Relief Gas Strengthens Acid.—While the relieving of acid and gas is an important part of the cooking process itself, it is also very essential, for the manufacture of the cooking acid, that this operation be properly conducted.

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The reclaiming process, and the "building up" of a strong acid, has become very important and typical for this continent, on account of the necessity of using a strong acid to cook the usually very wet wood in a comparatively short time. If the acid should become weak on account of too much weak relief liquor being returned to the acid, the relief liquor must pass through the separator, and only the gas may then be returned to the reclaim-

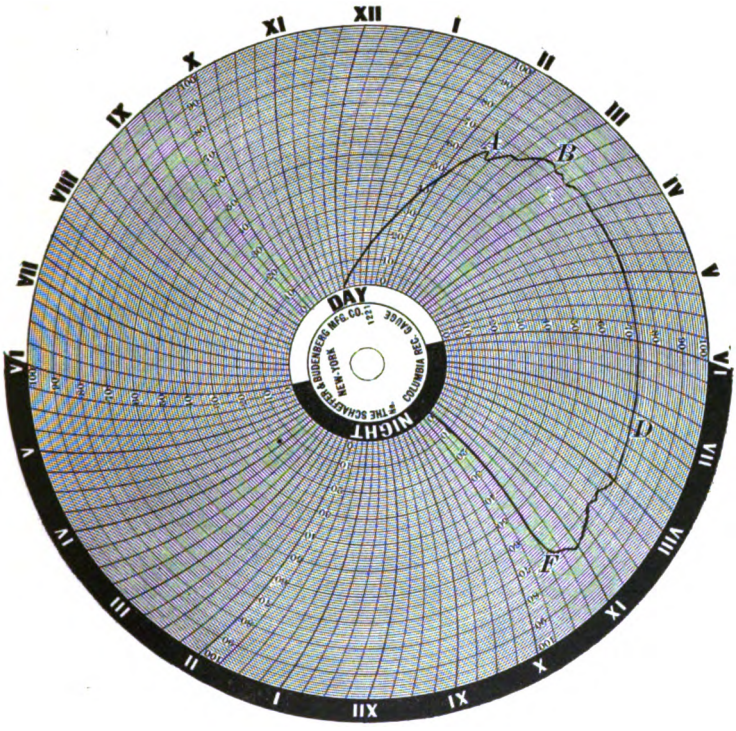

Fig. 29.

ing system, the liquor not being used. But even more necessary than a strong acid is a uniform acid; and in order to obtain uniform reclamation, the digesters must be properly *spaced*, that is to say, there should be a certain time between the steaming of each digester in the mill, of 1, 2, or 3 hours, depending upon number of digesters and cooking time.

103. No Standard Method of Cooking.—It is not possible to give any *standard* method of cooking; the process depends too much upon the nature of the wood, the composition of the acid,

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the desired quality of pulp, and, especially, upon the instructions issued at each plant, which are based upon particular experience.

With 10 or 11 hours cooking for easy-bleaching pulp, a temperature of 105° to 110°C. is usually reached after 4 hours, and this is gradually increased to 145° or 155°C., depending upon the wood and the acid. With shorter cooking time, the heating must be more rapid, and at times, a maximum temperature of

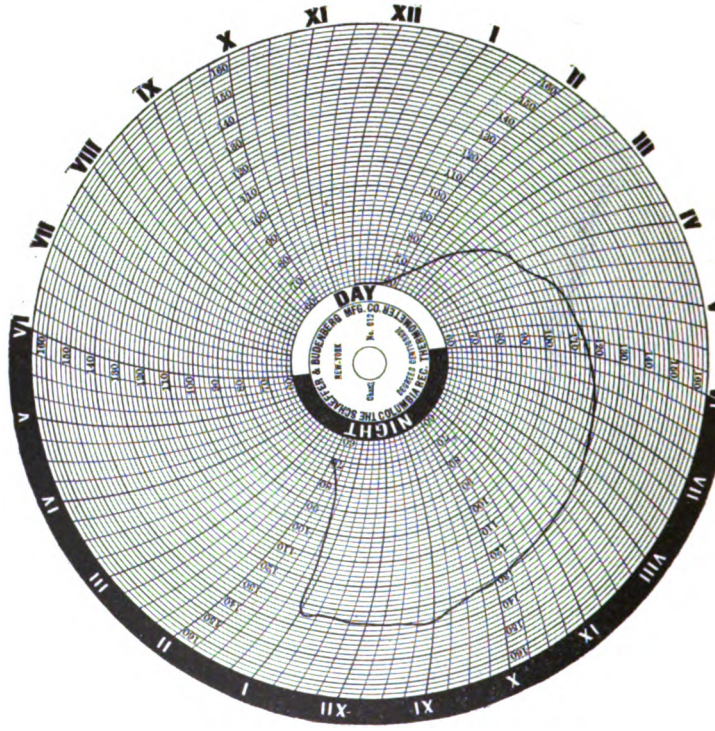

FIG. 30.

160°C. is reached, while in the slower cooking, the temperature is raised more gradually, and the maximum temperature is kept below 140°C. Figs. 29 and 30 show pressure and temperature charts for cooking sulphite pulp, for news print, in 9½ hours. The letters have the same significance as in Figs. 27 and 28.

104. Use of Superheated Steam.—Either saturated or superheated steam is used for heating the digester charge. The advantages of using superheated steam are less condensation

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and dilution and more rapid heating; but a high superheat should be avoided, on account of the danger of overheating the pulp at the steam inlet. Furthermore, the rapid heating with highly superheated steam undoubtedly causes a local overheating of the acid, which results in the escape of free SO_2 and a local loss of lime, the latter being due to precipitation of monosulphite, the danger of which has been explained.

105. Steam Consumption.—The quantity of steam admitted to the digester at the various stages of the process varies considerably, not only in the different mills but also in the same mill, unless the steam is measured by steam-flow meters. An attempt has been made at standardizing the steam consumption, throughout the cooking process, by adopting standard curves for the steam flow; and on the basis of this, an instrument for automatic control of the cooking process has been developed and is in use in a few mills.

106. Completion of the Cooking.—During the process of cooking, samples are taken of the liquor; and in well conducted mills, certain standards for acid test at the various stages of the cook are maintained. When the cooking is almost completed as shown by the tests, the steam valve *E*, Fig. 22, is closed, and the pressure reduced at *E*, Fig. 27, by relieving at the top, until the pressure is about 40 or 50 pounds at *F*, Fig. 27; at which time, steam valves, as well as relief valves, are closed, the blow valve is opened, and the charge is blown into the blow pit, through a blow pipe of cast iron or bronze. Usually the instructions are to blow the digester at a certain acid test; for instance, .25% to .3% SO_2, if the liquor is passed through a cooler, or a test of the hot liquor of .05% to .07% SO_2. This test is carried out as follows:

Ten cubic centimeters of the liquor sample is diluted with about 100 c.c. distilled water; starch solution is added, and the sample is titrated with N/32 iodine solution until the color changes into blue. Each cubic centimeter of iodine solution used corresponds to .01% SO_2 in the digester liquor.

107. Color Test.—If the progress and the endpoint of the cooking process be judged by the color of the liquor, a standard color scale can be made up of coffee solutions of various dilutions. The proportions of the coffee solution are as follows:

COFFEE SOLUTION.—Eight ounces of best coffee beans; 2 ounces

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of postum (cereal): and 2 ounces of chicory. Macerate thoroughly in a small quantity of cold water; add this mixture to 2 liters of distilled water; bring to boil over slow fire; and continue boiling from 30 to 45 minutes. Just before removing from boil, add the whole of an egg, partly beaten, and set solution aside to cool.

Now filter through cheese cloth, and through double filter paper, and then add 25 c.c. of formalin. Set this solution aside in amber bottle, as base color, and build color system by addition of distilled water, using the amounts indicated in the following table:

No.	Parts color solution	Parts water
1	1	10
2	1	9
3	1	8
4	1	7
5	1	6
6	1	5
7	1	4
8	1	3
9	1	2
10	1	1

These solutions are filled in a number of bottles and arranged to form a color scale. Behind these bottles should be a standard light source. Samples of liquor taken from the digester are filled in the same type of bottle and matched with the solutions of the color scale.

OTHER CONTROL TESTS IN COOKING PROCESS

108. Strength of Liquor.—The percentage of total, combined, and free SO_2 present in the cooking liquor at the various stages is determined as outlined in Art. **74.**

Toward the end of the cooking process, the value for free acid becomes higher than the value for total SO_2; this is due to the presence of organic acids formed in the process of cooking. But in mill practice, only the total SO_2 is usually determined.

Klason has suggested the determination of

(*a*) *half free* SO_2, that is the SO_2 that is combined as bisulphite;

(*b*) *free* SO_2; and

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(*c*) *loosely combined* SO_2, that is SO_2 which reversibly combined with the lignin.

In order to determine these three values, it is necessary to make three titrations as follows:

(*a*) One cubic centimeter of the liquor is diluted to about 100 c.c. with distilled water, and is titrated with N/10 iodine solution.

(*b*) One cubic centimeter of the liquor is diluted as above, and is titrated with N/10 sodium hydrate, using phenolphthalein as an indicator.

(*c*) This second sample is then over-saturated with alkali and allowed to stand for a few minutes. The solution is then acidified and titrated with N/10 iodine solution.

Assuming the first titration required *a* c.c. of N/10 iodine solution, the second titration required *b* c.c. of N/10 alkali solution, and the third titration required *c* c.c. of N/10 iodine solution,

$.32\ (a + c - 2b)$ = per cent of half free SO_2
$.32\ (2b - c)$ = per cent of free SO_2
$.32\ (c - a)$ = per cent of loosely combined SO_2

The decrease of the half free SO_2 and the increase of the loosely combined SO_2 shows the progress of the cooking process. At times the value for half free SO_2 may reach zero or even become negative. In such cases, the loosely combined SO_2 may leave its place in the lignin molecule and act as half free SO_2, combining with a different group of the lignin molecule, which results in a decrease of the amount of loosely combined SO_2 at the end of the process.

109. Mitscherlich's Ammonia Test.—The original ammonia test was meant to give an indication of the amount of lime present at the latter part of the cooking. The completion of the process was decided on the basis of the height and the appearance of the precipitate, and also on the color and smell of the liquor. The test was carried out in test tubes, about 8 inches long and graduated into 32 equal parts of the total capacity. Ammonia (1 : 1) is added in a volume, representing 1 of the 32 parts of the total of the tube, and the tube is made up with digester liquor, and shaken. After a few minutes, the height of the precipitate is observed. It was customary to consider the cooking finished when the height of the precipitate was about $\frac{1}{8}\frac{1}{2}$d of the tube.

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But this method is uncertain; and it is better to observe the point where the height of the precipitate no longer decreases, because at that point no more lignin is being dissolved.

110. The Blow Pit.—The blow pit is a large round tank built, similar to the acid tanks, of long leaf pine; or it is a square chamber of wood, or of concrete lined with wood, acid resistant brick, or tile. The capacity is about 2½ times that of the digester. At a distance of about 1 foot from the solid bottom, the blow pit has a false bottom made of wood, 2 inches thick, with perforations. These openings are ⅛ inch on the top side and widen toward the bottom side to ½ inch, and the distance of the holes from each other is about 1½ inches. In some mills, this false bottom may be made from perforated tile, and may be covered with cocoa matting. The perforated bottom is supported by lumber, which, in turn, is so supported as to leave a space of at least an inch between it and the solid bottom, to permit the free flow of the liquor and water leaving the pulp. Under the false bottom is a drain pipe, with plug cock, through which the liquor can drain off quickly. The blow pit is also provided with doors on the sides and often, also, on the top, for washing; it has also an opening that is connected with a large pipe, through which the pulp is either pumped to the rifflers and screens or flushed into tanks. Inside the blow pit, and opposite to the blow pipe, is a so-called **target,** of bronze or iron, against which the digester contents are blown, with the object of opening up the pulp and breaking up the chip form. At the top of the pit is an opening, which is large enough to allow all steam and gas from the blow to be carried off through a wooden stack that runs alongside and to the top of the digester building. Due to the sudden release from the digester of a large volume of pulp and liquor under high pressure, and to condensation of steam in the blow pit, pressure as well as vacuum may occur in the blow pit, and this should be considered in the construction of the blow pit.

111. Blowing and Washing.—Before blowing a digester, the blow pit is filled with water to about 1 foot above the false bottom, with the object of protecting this bottom as well as reducing fiber losses; it is often recommended to use warm water for this purpose. All openings are then carefully closed, and a water valve is opened on the line leading to the inside sprays, which are

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located in the upper part of the blow pit. The blow-off valve on the digester is then opened a little at first, but later on, completely, and the pulp is blown into the pit, the blowing being assisted by opening the steam valve *F*, Fig. 22, in the bottom fitting *T* and opposite to the blow-off line. Steam and gases escape through the vent pipe at the top opening; and, unless provision is made for the condensation of the steam and the cooling and recovery of the SO_2 gas, both steam and gas will go into the atmosphere, which is the usual practice.

If the digester does not blow clean, the pulp may be washed out with water from the top, but this requires a long time. It is better to close the blow valve, fill the bottom cone with water to a height sufficient to cover the pulp, and then introduce steam to loosen the pulp. The blow valve is finally opened and steam admitted through the steam valve.

The liquor is now drained off into the sewer, if the mill is not equipped with a plant for the recovery of by-products. The doors are opened, and, as soon as the liquor has drained off, the washing begins. Warm water is preferable; both because cold water may precipitate some of the lignin substance on the fibers and give them a dark color, which would require bleach for its removal, and because warm water drains off faster and dissolves substances better. For the same reason, the washing should begin immediately, and the waste liquor should not be allowed to remain in contact with the pulp for a long time after blowing. At times, kerosene is added in the blow pit for elimination of troublesome pitch.

The washing process may be carried out by filling the blow pit with water, after the liquor is drained off, and then permitting the water to drain off, repeating this operation several times. Or the drain water is allowed to run off continuously, the washing being continued by means of high-pressure hose streams through the various openings in the sides and top. The washing takes several hours, and lasts until the wash water shows no color from the liquor. A still better washing may be obtained with wash drums, working as pulp thickeners.

INDIRECT COOKING PROCESS

112. The Mitscherlich (Indirect) Cooking Process.—This process is an indirect cooking process, and it requires a digester

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which in construction is slightly different from the Ritter-Kellner digester.

The digester is usually of the vertical type already described, but a horizontal digester may very often be used. In the lower part of the Mitscherlich digesters, the heating pipes are located. They are of hard lead or of copper, the former having the advantage of less repairs and longer duration, while the latter have the advantage of a better heat transmission. The diameter of the pipes varies, being usually between $2\frac{1}{2}$ and $3\frac{1}{2}$ inches, and the total heating surface of the pipes may vary between .07 and .2 sq. ft. per cubic foot of digester capacity, depending upon such factors as the type of digester (vertical or horizontal), arrangement of coils, cooking time, and temperature of steam (pressure and superheat); .13 sq. ft. of heating surface per cubic feet of digester space may be considered a satisfactory arrangement for most conditions. The circulation in the digester with indirect heating is naturally not so good as with the direct heating; it is claimed that with the vertical Mitscherlich digester, the liquor circulates upward along the digester walls (since the heating coils are located around the circumference) and moves downward in the center, while in the Ritter-Kellner digester, the circulation is in the opposite direction.

The temperature is more uniform in the horizontal digester, particularly in the rotating type that is used in some mills. Also, the mechanical disintegration of the chips due to the rotation of the cooking vessel, is considered an advantage for the latter type.

In Fig. 31 is shown a typical Mitscherlich digester of the stationary horizontal type, which is used in an American mill for slow cooking. The total length of this digester is 40 ft., and the inside diameter is 12 ft., the capacity being 4136 cubic feet. The heating coil consists of lead pipe with an outside diameter of $1\frac{1}{4}$ inches and an inside diameter of $\frac{1}{2}$ inch and a total length of 312 feet, corresponding to a heating surface of 120 sq. ft. The pipes are located at the bottom of the digester, the steam entering and leaving the coils at A and B, respectively. The chips are blown into the digester through the two openings C_1 and C_2 by means of a steam injector. Direct steam is then applied at D until it comes out at the diametrically opposite bottom cover E_2. The four covers are tightened, and acid is pumped in at F until it reaches the required level, it being important that the acid cover

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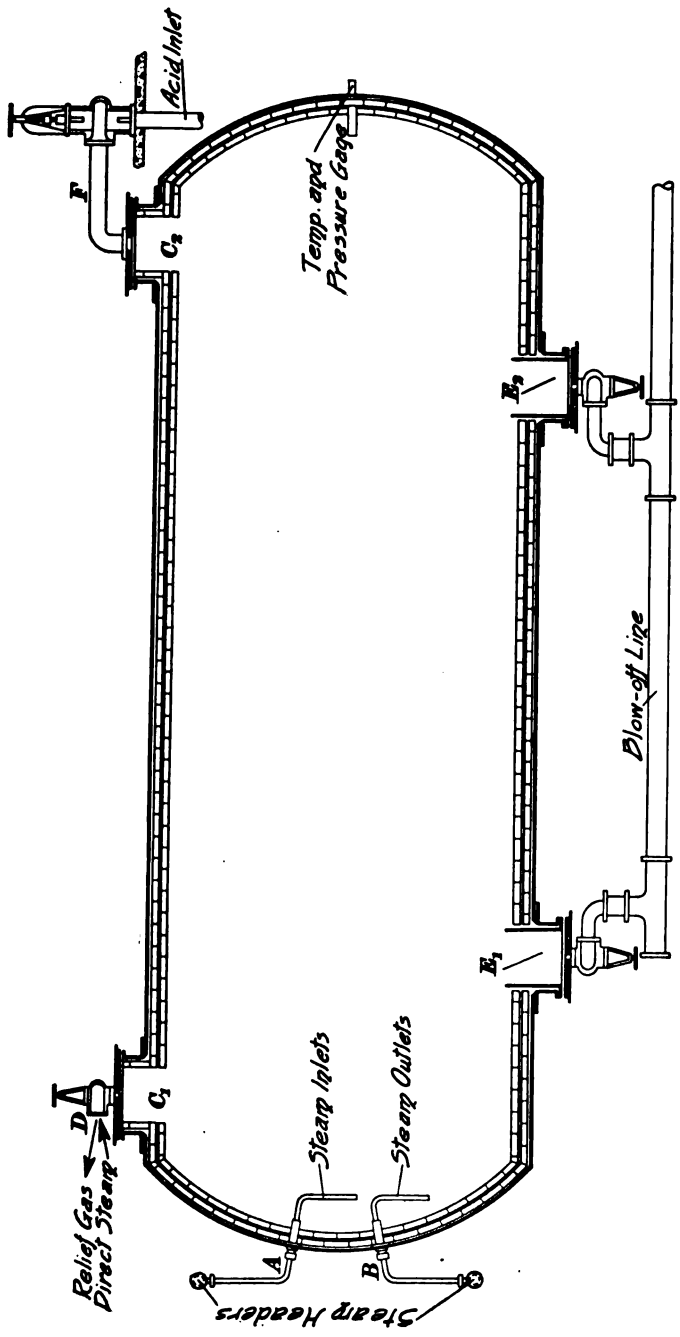

FIG. 31.

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the chips completely. It is also part of the object of the steaming process to make the chips heavy, in order to prevent them from floating on the acid. Another advantage of the steaming of the chips is the improved penetration, the theory being that when the cold acid is added, the steam in the chips condenses, creating a vacuum in the chips, which assists the penetration. When the cooking is completed, the pressure is reduced to 10

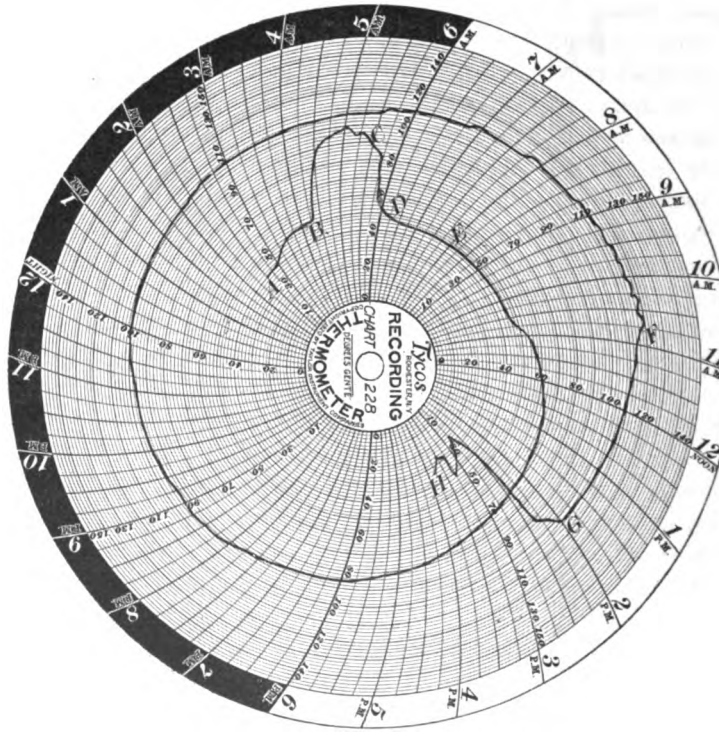

FIG. 32.

lb., by relieving through the relief line at *D*. The waste liquor is then blown into the sewer, and the digester is filled with water and again drained. After the bottom strainers at E_1 and E_2 are removed, the digester is filled with water and the bottom covers tripped, allowing the stock to drop into the pits. (This method of emptying the digester is also used in European Ritter-Kellner mills.)

Referring to Fig. 32, the temperature chart represents a typical slow cook with a digester of the above construction. The total

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cooking time is in this case 38 hours, including 1½ hours for direct steaming of the chips and 3½ hours for washing and emptying. On the curve, the distance from *A* to *B* shows the time consumed in filling in the chips. From *B* to *C*, the chips were steamed, and the acid was pumped in from *C* to *D*. The distance from *D* to *E* on the curve represents the time consumed in putting on covers and preparing for the heating. Steam is admitted to the coils at *E;* the relieving of gas is begun at *F*, and is continued to *G*. The time from *G* to *H* is occupied with washing and emptying. The maximum temperature is 120°C. and the maximum pressure is 60 lb.; but it is not unusual to allow the temperature to reach even 130°C., or slightly more, in the quicker Mitscherlich cooks, in which case, the increase of temperature in the beginning of the process must be more rapid.

The typical Mitscherlich pulp is characterized by its strength and its beating qualities.

113. The Morterud Cooking Process.—This is also an indirect cooking process. But, while in the Mitscherlich process, the digester charge is heated by means of steam pipes placed in the interior of the cooking vessel, the liquor, in the Morterud process, is heated outside the digester in a separate heating apparatus, which consists of a cylindrical vessel, in which a battery of steam pipes is placed. This system is fully explained in the Section on *Sulphate Pulp*. The liquor is continuously leaving the bottom of the digester, which is equipped with a large strainer, to hold back the chips, and is forced by a pump through the heating apparatus to an inlet at the top of the digester. During this continuous and rapid circulation, the liquor is heated without being diluted. The idea, which combines some of the advantages of the direct and the indirect processes already mentioned, has been successfully employed in the alkaline cooking processes; but, up to the present time, it has not proved to be a success in the sulphite process, because of mechanical difficulties, which, no doubt, will be overcome. It is suggested, in connection with the use of this system of cooking, to transfuse a quantity of hot liquor from a digester that is near the blowing point to the digester just being filled, thus saving heat, time and some sulphur.

Transfusion of liquor from one digester already at high temperature to another which is being started up has also been recommended for the ordinary cooking processes, especially

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the indirect process, and it is claimed that, in addition to the advantages already mentioned, the organic acids in the transfused liquor have a favorable influence on the cooking process.

PULP, ACID, RAW MATERIALS, AND WASTE LIQUOR

YIELD AND QUALITY OF PULP

114. Yield of Pulp.—It was mentioned that the resins in the wood are only to some extent dissolved in the cooking process. Resinous woods are therefore not suitable for the sulphite process, unless the resin is previously extracted, and only the less resinous woods, such as the spruces, balsam fir, and hemlock are commonly used. Small quantities of white fir, tamarack, yellow pine, and poplar are also used in this process.

The cellulose content of the wood varies considerably within the same species grown in different localities as well as with the different woods, spruce usually being higher in cellulose than balsam fir and hemlock. The yield of cellulose in the cooking process naturally depends upon the cellulose content of the wood; but it is also dependent upon the method of cooking, particularly the temperature and the circulation in the digester. It is generally found that wood contains from 50 to 55% of cellulose; but this cellulose is no doubt a mixture of various forms of cellulose and other hexosans and of pentosans. In the commercial processes, such high yields are practically never reached, on account of the fact that these carbohydrates, even celluloses, are attacked at high temperatures, being hydrolyzed into soluble sugars. The more carefully the process is conducted the smaller is the loss of fiber weight, due to destruction of these substances, and the higher is the yield of pulp. In quick cooking, such as is usually practiced in news mills, it is necessary to employ temperatures as high as 150° and even 160°C.; but this is always at a cost of yield and quality.

115. The yield of good fiber is also dependent upon the amount of screenings, which again depends upon the circulation in the digester and the penetration. It is obvious that if the chips are not sufficiently penetrated by the acid at the temperature where the lignin is beginning to go into solution, or at about 105°C., the surface of the chips is cooked before the interior, or the sur-

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face is overcooked before the entire chip is softened. The result is a mixture of overcooked and undercooked fibers and a high percentage of screenings. It is accordingly advisable to secure a good penetration at low temperature. The penetration depends upon the size of the chips, and these should therefore be as uniform in size as possible. Furthermore, the moisture of the chips and the density of the wood are factors to be considered. A moisture content of 25% to 35% is apparently the most satisfactory with the average wood, while with very dry chips the penetration is slower, due to the presence of air in the chips and to the dry condition of the cell wall.

Steaming of the chips before the acid is introduced is intended to equalize the moisture of the chips and to improve the penetration as explained above. Experimentally, it has been found that an acid with a high free SO_2 content penetrates more rapidly than a weaker acid, and, also, that a high combined SO_2 causes a slow penetration. It is often attempted to improve the penetration, particularly with wet wood, by holding the temperature of the digester at about 100°C. for an hour or two. There is a danger of losing the circulation by shutting off the steam at this point; but with several steam inlets through the walls of the bottom digester cone, it is usually possible to obtain good circulation, even if the chips 'settle.'

116. The yield is often expressed in cords per ton, or pounds of pulp per cord, or per cubic foot of digester space. The first may vary between 1.7 and 2.2 cords per ton of pulp, and the last may be between 4 and 5 pounds per cubic foot, depending upon the factors mentioned already, but probably depending most upon the density of the wood.

This is a factor which is not sufficiently appreciated, in spite of the fact that the amount of actual wood weight per cord, as well as the weight of chips per cubic foot of digester space, naturally varies considerably with the specific gravity (the density) of the wood. Expressed in these terms, a true figure of the yield due to the cooking operation itself is only obtainable when the actual weight of the wood per unit of volume is known. But this should be known also for the control of the cooking process, since it is customary to judge the progress of the cooking by means of titration tests or color tests of the liquor, to indicate to what extent the wood is dissolved. The amount of lignin in solution in the liquor at a certain point in the cooking, and

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therefore, also, the color of the liquor, depends largely, of course, upon the density of the wood or, what is the same thing, the proportion of wood to acid.

117. Quality of Pulp.—The trade calls for a number of different grades of pulp according to its intended use. An easy-bleaching pulp can be produced either by quick cooking or by slow cooking. In both cases, it is desired to remove the lignin as completely as possible; but, in the former case, this can only be accomplished by going to a very high temperature and to "cook down" to a low acid test. As a rule, the pulps resulting from these cooks are mixtures of very easy-bleaching fibers with incompletely cooked fibers, and the attack on the fiber is apparent in its beating qualities. With a long cooking time it is possible to remove the lignin almost completely, without injury to the fiber, and the operator has it more nearly under his control to regulate the pliability and beating quality of the pulp.

118. The hydration of the fiber in the beating process is undoubtedly influenced by the presence of residual impurities from the wood, as well as by decomposition products of the cellulose. An overcooked, soft fiber will hydrate easily, but will very soon decrease in strength; while fiber which is not injured in the process of cooking, can be hydrated to a great extent before the strength drops down. This is the reason why Mitscherlich pulp is particularly suitable for grease-proof papers, which require maximum hydration. Uniformity of chips with regard to size, moisture content, and density was mentioned as an important factor in penetration, and also of yield and quality. Even more important is uniformity with regard to wood species. On account of the chemical and physical difference between spruce, balsam fir, and hemlock, these woods should not be cooked together; and, wherever possible, the species should be sorted separately in the yard, and should be cooked separately.

Decayed wood should also be avoided, because it gives a low yield per unit of volume, and a pulp of inferior strength and beating quality.

119. Dirt in pulp originates usually in the woodroom when the bark is incompletely removed; but the pulp may also contain uncooked particles, especially in the quick cooking, or pieces of knots, which are disintegrated into small pieces as the pulp is blown against the target in the blow pit. Dirt from this latter

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cause is greatly reduced by blowing at a low pressure, or by washing the pulp out of the digester, or, also, by constructing very long blow pits. The blowing of the digester at high pressure has undoubtedly also an unfavorable effect upon the fiber, due to the sudden release of pressure, which, it is claimed, causes practically an explosion of the individual fibers. Dirt may also get in from accumulations in pipe lines, exposed tanks, etc.

ACID, RAW MATERIALS, AND WASTE LIQUOR

120. The Best Acid.—The effect of a high percentage of free SO_2 in the cooking acid is to produce a more rapid cooking, which is probably due, largely, to a catalytic effect of the free acid. The advantage of a high free acid for penetration has already been mentioned.

The percentage of combined SO_2 is known, as far as the minimum requirement for the cooking process is concerned. Experience has shown that below .9% combined SO_2, there is a probability of obtaining a raw incompletely cooked pulp; between .9 and 1.1% combined SO_2 is favorable for the production of easy-bleaching pulp; while with a high percentage of combined SO_2, the pulp becomes harder, unless the cooking time is materially increased, in which case, a very uniform pulp may be obtained.

121. Raw Materials Used per Ton.—Wood is the most important raw material in the sulphite process, and the quantity of wood used to produce a ton of air-dry pulp naturally varies considerably with its quality. From 1.7 to 2.2 cords of rough wood may be used per ton of pulp, depending upon the soundness of the wood, its density and chemical composition, and upon many factors in the manufacturing processes, as mentioned in the discussion of yield, Arts. **114–116.** It is also obvious that the wood consumption varies with the quality of the pulp, easy-bleaching pulp usually requiring more wood per ton than a very strong pulp, under average methods of manufacturing. There is still greater variation in the amount of sulphur per ton of pulp; because this depends a great deal upon the yield in the cooking process, and still more, upon the efficiency of the acid plant, especially of the recovery system. While it should be possible in commercial operation to produce pulp with 200 pounds of sulphur per ton continuously, the actual sulphur consumption in mill practice varies between 220 and 300 pounds per ton of

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pulp. The quantity of limestone or lime varies with the yield of pulp, and also with the composition of the acid, which may vary from .9% to 1.3% combined SO_2, or more; and the excess lime in the liquor is not recovered. About 2300 U. S. gallons of acid are used per ton of pulp; accordingly, from 260 to 370 pounds of limestone or from 150 to 210 pounds of lime may be consumed.

122. The steam consumption will, of course, also vary to some extent but 2.75 pounds of steam per pound of pulp, or 5500 pounds per ton, is probably a fair figure. The largest quantity of steam is consumed in heating the large volume of acid and the chips; and the total steam requirement per ton varies according to the temperature of the acid as it enters the digester and, also, with the proportion of acid to wood. In order to save steam, it is therefore advantageous to fill the digester with as great a quantity of chips as possible; in Europe, special mechanical devices have been designed to distribute and press the chips together in the digester.

A considerable reduction in steam consumption is also effected by transfusion of liquor, as described above. The heat losses due to radiation from the digester can be reduced by effective insulation, the value of the insulation increasing with the increase in thickness of the digester lining, since this in itself forms a good insulation.

123. The steam consumption with easy-bleaching pulp and strong pulp may be seen from the following figures which are average figures for a number of direct cookings.

Capacity of digester	5785 cu. ft.
Temperature of steam	230–270°C.
Pressure in steam line	90–100 lb., gauge
Acid	31,700 U. S. gallons
Temperature of acid	26°C.
Volume of chips	3175 cu. ft.
Maximum digester temperature	140°C.

	Easy-Bleaching	Strong
Time of cooking, hours	15–18	11½–18
Yield of pulp, pounds	27,500	29,260
Steam consumed, pounds	64,636	60,500
Pounds steam per pound pulp	2.40	2.10

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The distribution of the steam consumption throughout the cooking was, for easy-bleaching pulp, as follows:

Cooking, up to 105°C., 44,785 pounds of steam;

Cooking, from 105°C. to 140°C. 19,666 pounds of steam.

In other words, 69.5% of the total steam consumption is used in heating the digester charge up to 105°C.

124. Utilization of Waste Liquor.—In the sulphite cooking process, the cellulose substance is separated in the form of pulp from the non-cellulose compounds of the wood, which go into solution and are discharged with the waste liquor. These compounds represent more than 50% of the total weight of the wood, and they consist chiefly of reaction products of the lignin, sugars, and resins of the wood. On account of the many complicated reactions that take place during the cooking process, the chemical composition of the waste liquor is known only to a very limited extent. This is the main reason why it has not as yet been possible to recover and utilize properly the organic substances in the waste liquor; and the very few processes of utilization that have reached any commercial importance, are based upon the recovery of a mixture of many different compounds, rather than upon a separation of the various compounds and their refining, according to their chemical properties. One difficulty in the recovery of the waste products of the liquor is that they are present in a very dilute form, the solids representing only 11 to 12% of the total liquor. In other words, for every ton of pulp, approximately 9 tons of liquor with 1.2 tons solid substances have to be handled; this means very large storage capacity.

125. If the liquor is evaporated to a high concentration, a product with adhesive properties is obtained, which may be used as a road binder, a binder for briquetting powdered materials, or as a core binder in foundries. The concentrated liquor is also used as a tanning material. Evaporated to dryness, or to about 50% concentration, the substances may be utilized as a fuel, or they may be subjected to a distillation process.

The solid substances may also be separated from the liquor by precipitation at high temperature and pressure, the recovered dry substance being used as fuel or in a distillation process. Other processes for the utilization of the waste liquor, as a paper

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sizing material, an adhesive, a tanning material, cattle food, and fertilizer have been suggested, and they are in use to some extent in other countries. The base of certain sulphur dyestuffs is also present in the waste liquor.

The manufacture of pulp has been likened to the making of pulp from coal; the non-cellulose substances in the waste liquor from the pulp correspond to the distillation products (coal tar, etc.) from the latter.

126. The processes of manufacturing ethyl alcohol from waste liquor have received much attention during recent years. The higher sugars in the wood are hydrolysed, during the cooking process, into fermentable sugars. The free SO_2 is removed by heating and by neutralization, either after the liquor has been partly concentrated or in its original strength, or its effect may be counteracted by aeration. Yeast and yeast food are added, and the fermentation continued for 70 to 90 hours, after which time, the alcohol is distilled off. A yield of 95% alcohol amounting to about one per cent by volume of the original liquor is usually obtained.

QUESTIONS

(1) Give the operations performed in the digester room.

(2) Referring to Question 1, what points are to be especially watched?

(3) What becomes of the gas that goes off in the relief from a digester?

(4) How is the quality of the pulp affected by the time of and temperature of cooking?

(5) Mention the advantages and disadvantages of the use of superheated steam for cooking.

(6) Describe a blow pit, and explain what takes place in it.

(7) Mention some of the factors that influence the yield of pulp; explain how they act.

(8) What precautions should be taken to obtain a high-quality pulp?

(9) (*a*) What substances are contained in the waste sulphite liquor? (*b*) how can they be utilized?

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MANUFACTURE OF SULPHITE PULP

EXAMINATION QUESTIONS

(1) What materials are used in making sulphite pulp?

(2) Name the principal features of the three types of sulphur burners.

(3) Why is it necessary to have careful control of the temperature in the sulphur burner?

(4) How does the burning of pyrites differ from the burning of sulphur?

(5) Write the equations for all the reactions in the preparation of cooking acid (*a*) by the milk-of-lime system, and (*b*) by the tower system.

(6) What is the effect on the cooking acid of the recovery of sulphur dioxide?

(7) Why is the presence of sulphur trioxide detrimental in burner gas?

(8) Mention the reasons for the recovery of sulphur dioxide.

(9) What effect does cooking with sulphite have on the constituents of wood?

(10) What happens to the bisulphite in the liquor during the progress of the cook?

(11) Name the essential parts of a digester, and mention the function of each.

(12) (*a*) How is a digester lined? (*b*) why is an acid-proof lining necessary?

(13) Explain the purpose and the operation of relieving the digester.

(14) How does the cook know when to blow the digester? Explain one test.

(15) Compare the Mitscherlich process with the Ritter-Kellner process as to equipment, time, and temperature of cooking.

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SECTION 5

MANUFACTURE OF SODA PULP

By ARTHUR BURGESS LARCHAR

INTRODUCTORY

OBJECT OF THE PROCESS

1. The Fibrous and Non-Fibrous Parts of Wood.—Peeled or barked wood may be regarded as made up of two very different substances: one is *fibrous*, and it consists of short, thin, wood cells, or fibers; the other is *non-fibrous*. The two are closely combined in the wood, and in the so-called *mechanical process* of pulp making, no effort is made to separate them. Since the non-fibrous part is much more easily changed by the action of air, sunlight, and moisture than the fibrous part, this causes paper that is made from groundwood (mechanical) pulp to change color and to become brittle and worthless with the lapse of time. But, by boiling the wood in a solution of water and chemicals, the non-fibrous part may be changed and dissolved, which leaves the fibrous portion nearly pure.

The aim of all chemical processes of pulp making is to separate the fibrous part of the wood, which is called **cellulose,** from the non-fibrous part by dissolving the latter in the solution above referred to. The separation is not complete; for some of the coloring matters in the non-fibrous part, which consists of lignin, resins, gums, sugars, coloring matter, etc., remain in the fibers, and some of the fiber is dissolved in the process. The most successful process is that which will perform the separation with the smallest loss of fiber.

The oldest chemical process for making pulp is called the **soda process,** so called because caustic soda NaOH is the chemical

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used; the product that results from this process is called **soda pulp.** In the United States, this process has developed principally since 1880. The greater part of the soda pulp manufactured on this continent is made in Maine, New York, and Pennsylvania; a little is made in the South and West, and a small amount is made in Canada.

2. Kinds of Wood Used for Making Soda Pulp.—The kinds of wood that have been found best suited to pulp making by the soda process are those from the broad-leaved trees, the majority of which shed their leaves in the winter and are called *deciduous* for this reason. First in order of importance is *aspen*, usually known as *poplar;* white maple, birch, chestnut, balm of Gilead (or cottonwood), gum, and basswood are also used. Wood from evergreen, cone-bearing trees, such as the pines, spruce and balsam fir, are being used to some extent. Soda pulp made from aspen or similar wood is put into papers when soft stock is desired; it enters into book, magazine, and writing papers, and it serves as a filler to complete the furnish made up largely of longer fibers.

Owing to the shortness of the fibers in soda pulp, it does not make a strong paper; but papers in which it is used may be readily finished to a good surface.

BRIEF OUTLINE OF THE SODA PROCESS

3. The Wood.—Peeled wood may be delivered to the mill from nearby points by teams or from distant points by railroad cars; in either case, it is cut or sawed into 4-foot lengths. Mills that are favorably situated may get their wood in log lengths direct from the forest, by floating or driving it down the stream; when this method is used, a cutting-up or slasher mill cuts the logs into 4-foot lengths. Broad-leaved woods other than poplar are not usually driven, owing to their liability to sink. A 50-mile drive is about the limit for distance.

The wood (in 4-foot lengths) is conveyed by industrial cars or by carriers to a wood-preparing room, and is there cut into chips by chippers, the lengths of chips desired varying from $\frac{3}{8}$ to $\frac{7}{8}$ inch. The chips are elevated to chip bins over the digester, and they are run into the digesters by gravity. The preliminary operations are described in the Section on *Preparation of Wood.*

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4. The Soda Process.—The caustic-soda liquor goes into the digester with the chips, the digester head, or cover, is bolted on, and the contents is cooked by admitting steam into the digester. After the cooking is complete, the mixture of pulp and liquor that contains the dissolved part of the wood is discharged into a blow-pit, and from this into washing tanks or pans, where the pulp is drained and washed, to free it from the colored liquor; the latter is boiled down in evaporators, and is treated in the reclaiming department to recover the soda contained in it.

The washed pulp is screened, thickened, and bleached; the bleached fiber is freed from chemicals in drainers or washers, and is run into a sheet on cylinder drying machines. The pulp is shipped to the paper mill in the form of rolls or bales. In case the pulp mill and the paper mill are close together, the drying machine is not used, and the drained pulp is then furnished directly to the beaters from storage tanks.

The black liquor from the washing tanks, after being thickened by boiling in multiple-effect evaporators, is burned in rotary furnaces to form black ash, which contains soda ash (sodium carbonate, Na_2CO_3) to the extent of about $\frac{4}{5}$ths (80%) of its weight. This black ash, which is what is left when the black liquor is burned, is leached, and the soda ash thereby dissolved in water is pumped to the causticizing department, or liquor room, where new caustic liquor is made from it.

The diagram, or flow sheet, Fig. 1, shows the course through which the materials move in the different stages of the soda process; it should be carefully considered in connection with the statements in this and the preceding article.

The manufacture of sulphate pulp has much in common with the making of soda pulp; because of this, and because of the slightly different treatment of the subject, it is recommended that the Section on *Sulphate Pulp* be also carefully studied by the student interested in the soda process.

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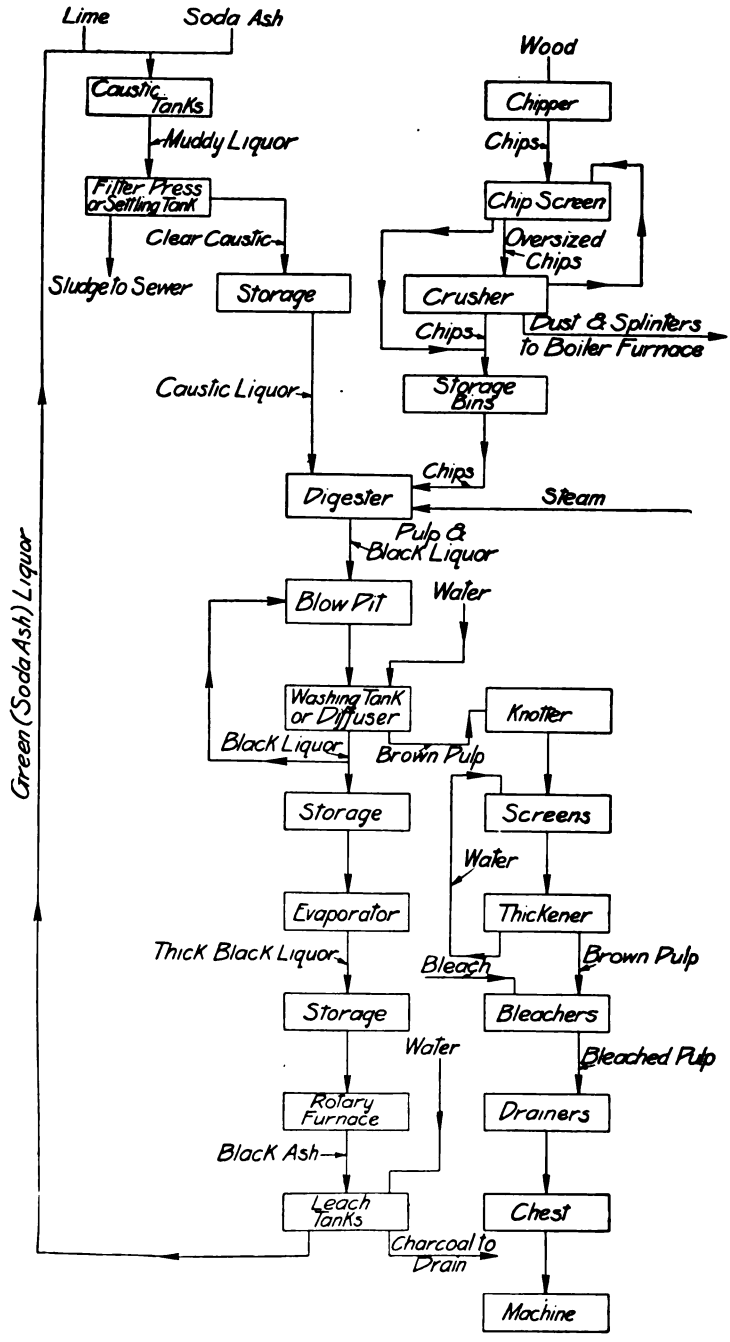

FIG. 1.

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THE COOKING LIQUOR

PREPARING THE COOKING LIQUOR

CHEMICALS USED

5. Soda Ash (and Electrolytic Caustic).—The chemicals used in the soda process to dissolve the non-fibrous part of the wood will now be discussed.

Caustic soda, usually called **caustic** in the mills, is the chemical that enables the cooking liquor to act; it is called **sodium hydrate** (or sodium hydroxide) by chemists, and it has the molecular formula NaOH. In what follows, the word **alkali** will sometimes be used instead of caustic or soda ash when referring to the chemicals used in the soda process.

Two methods may be used to prepare caustic in the soda mill:

6. By the *first method,* the caustic (NaOH) is prepared from another compound of sodium, which is called **soda ash** or **sodium carbonate,** and which has the molecular formula Na_2CO_3. Soda ash is a heavy, white powder, and comes to the mill either in bulk carloads or in burlap bags that hold a few hundred pounds each. Soda ash has been made for a long time from salt, the most abundant compound of sodium, and upon a large scale, both in Europe and in the United States. Soda ash dissolves freely in water, and dissolved soda ash is what is being constantly made in the reclaiming department of the soda mill.

It is clearly to be seen that if new caustic liquor is to be made from the dissolved soda ash that has been reclaimed on the premises, it can be done most cheaply at the mill; and that is where it is done—in the liquor room, or causticizing department, of the mill.

Boiling soda-ash liquor with lime yields caustic soda; thus,

$$Na_2CO_3 + CaO + H_2O = 2NaOH + CaCO_3$$

7. By the *second method,* the electric current is used to make the caustic for the cooking liquor. Brine, made by dissolving salt (NaCl) in water, is acted on in suitable cells by the electric current, and caustic-soda liquor is one of the direct products of this process (see Section on *Bleaching of Pulp*). Many of the larger soda mills have electrolytic departments in which caustic is made.

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As will be seen later, not all of the soda ash that goes into the liquor room to make caustic is returned to it as reclaimed ash after passing through the digesters and reclaiming department; some loss is bound to occur. To make good this loss, new soda ash or caustic that has been made electrolytically may be used.

From the foregoing, it is clear that the reclaimed soda ash, which has already passed through the process, is the chief substance employed in preparing caustic-soda cooking liquor; while fresh soda ash or caustic soda from the electrolytic plant or both, serve to replace the material lost in the process.

8. Lime.—Soda ash alone will not dissolve all the non-fibrous part of wood, although it has some dissolving and softening effect when wood is digested or cooked with it. Before it can be of use, it must undergo a *chemical change*, and this is brought about by boiling dissolved soda ash with slaked lime. **Lime**, therefore, is a very important material in the operation of a soda-pulp mill. This substance, which is so commonly used in preparing mortar and plaster in the building trades, is what is left when limestone (calcium carbonate, $CaCO_3$) is calcined, or burned, in a kiln or furnace; it is also called **quicklime** and **caustic lime**, and has the molecular formula CaO. Quicklime should not be left exposed to the air, since it then absorbs carbon dioxide from the air and reverts back to the carbonate again.

Slaked lime, or **calcium hydrate** (also called *calcium hydroxide*), $Ca(OH)_2$, results when lime and water are brought together, the reaction being expressed by the equation,

$$CaO + H_2O = Ca(OH)_2,$$

and considerable heat is given off during the reaction.

It is best to use the purest lime for caustic-liquor making; any sand and clay-like impurities are likely to frit into small masses, which do not slake in the caustic liquor tanks and remain behind to clog the drains, when these are washed out. The presence of magnesia is a detriment; it is useless in causticizing, and it is generally believed that magnesia limes give trouble from slow settling.

A well burned, but not over burned, lime is required in liquor making. Unburned stone or core is a nuisance; it is too heavy to wash away with the lime sludge, and it may be large enough and hard enough to cause breakage of the agitator arms.

Different limestones give limes that act differently in settling.

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A pure, well burned lime, one that yields a rapid-settling sludge in the caustic tank, is the kind the liquor maker wants.

9. Water.—The third important material used in making caustic liquor is water; pulp cannot be made from dry materials.

The quantity of water required for liquor making is not far from two gallons of water to one pound of soda ash used; this allows enough water to wash away the mud after drawing off the liquor, and to wash floors and drains. The water need not be filtered, since the liquor is cleared by the settling of the lime mud. It must, however, be free from light particles of carbon, such as coke or charcoal, as this often floats and makes trouble with the quality of the pulp. Much of the needed water comes into the causticizing department with the reclaimed soda ash. The hotter the water that is used in making the caustic the better, as it saves steam in the causticizing tank and speeds up the work in the liquor room.

STORING AND CONVEYING COOKING LIQUORS

10. Tanks.—The boiling together of soda ash and slaked lime is carried on in *tanks*, which may also be used for settling the liquor, or other tanks may be used for this purpose. Still other tanks are used as storage vessels for the clear, finished liquor, ready for the digesters.

Although these tanks may be of various styles and shapes, the round, flat-bottomed, upright, open-topped tanks are most generally employed, and steel plate is the material universally used for the construction of caustic tanks. Carefully riveted and calked seams must be insisted on, in order to secure a tight job; and thick plate is required on the bottom, to withstand the grinding of the lime sludge upon it, when the liquor is stirred.

11. In order that the liquor and lime, as *sludge*, may be well mixed together, the tanks in which the boiling and mixing are done are equipped with agitators or stirrers. For vertical tanks, such as is shown in Fig. 2, these stirrers are secured to heavy cast-iron arms A, which are bolted to a steel shaft that stands plumb, in the center of the tank, with its lower end in a guide or step T; at the upper end is a bevel gear K, meshing with a pinion, driven by belt pulleys, as shown, the power required being transmitted from the main-line shafting. The stirring arms may

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be flat, but are set diagonally to the bottom of the tank, and are made to turn in such a manner that the material will have a tendency to be lifted by the revolving of the agitator. Some tanks have agitators built like a screw propeller.

Tanks have one or more connections on the side, near the bottom, for removing the clear liquor, and they have an opening *O*

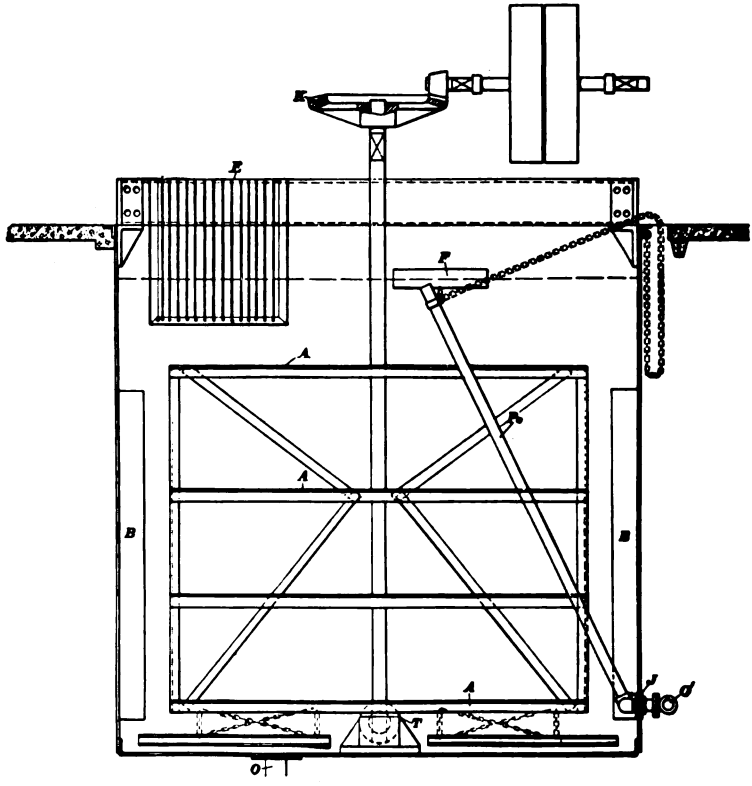

FIG. 2.

in the bottom for removal of the lime sludge. The clear liquor is drawn off through the pipe P_0, hinged at J, which permits the other end of the pipe to swing through an arc of a circle, thus raising or lowering F. As the level of the liquor falls, the upper end F of the pipe follows it, and it is kept by the chain in the same position relative to the upper surface of the liquor. This arrangement permits clear liquor to be drawn from the tank without drawing the lime mud with it, the liquor passing down the

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pipe and out through O'. The agitator is, of course, stopped while the pipe is draining the liquor.

12. Caustic tanks similar to that illustrated in Fig. 2 may have baskets E of iron rods or perforated plates hung in them near the top. The lime is placed in these baskets, which thus keep any unburned core from getting into the tanks. The size of the tanks is likely to vary with the size of the mill, the space available, and the particular method of operating that is selected.

Good agitation is obtained in a rectangular tank, Fig. 3, which has a half-cylindrical bottom and an agitator on a horizontal shaft; the upper half of the tank may complete the cylinder or it may have vertical sides. The scrapers S on the agitator shaft

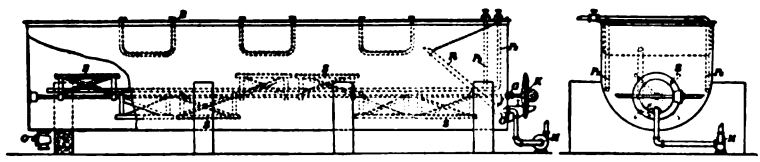

FIG. 3.

will then lift the lime sludge part way up in the tank and let it fall back through the liquor or wash water, thus giving a good mixing. The lime baskets, B, swivel pipe, P_0, etc., have the same functions as in the vertical tank.

The arrangement of a causticizing room in a soda pulp-mill requires convenient means of bringing lime and soda ash from bins and for weighing these into the tanks; a pipe line for the recovered soda liquor must also be provided. In so far as possible, the liquids should flow by gravity from tank to tank.

13. Pumps.—Liquids in the caustic-making department are moved by pumps from tank to tank, unless the tanks are so placed that the liquids can flow by gravity. These pumps are a very important feature of the mill; they must be working all the time or, at least, the greater part of the time; they must run fast enough to keep the mill running at full production; they must not leak, for leaks mean loss of valuable material; and they must run without frequent renewals or repairs, because shutting down a pump for repairs often means a stoppage of the entire department.

The centrifugal type of pump is the one best adapted to use in the liquor-making department. In this pump (described in the Section on *General Mill Equipment*, Vol. V), a cast-iron impeller,

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or runner, is keyed to a shaft and revolves in a cast-iron shell, or casing. The liquid is brought into the pump at the center of the runner, and the vanes of the whirling runner throw the liquid against the shell of the pump. A discharge opening on the rim of the shell guides the liquid into the discharge pipe. The centrifugal pumps may be belt driven from a main or counter shaft, or they may be direct connected to an engine or electric motor. Being heavy, simple, and made of cast iron, they stand hard usage and gritty liquids very well. Pumps should be set in a well-lighted, clean place, and they should have sufficient room around them to allow them to be easily inspected, packed, and repaired.

14. Piping.—Either wrought-iron piping or the best grade of steel piping is used for the conveying of caustic liquor, and a great deal of trouble can be prevented by proper arrangement of the piping. While the size of the pipe used depends on the amount of liquid conveyed, it is better to have the piping larger than is necessary rather than too small; 4-inch piping is about right for most liquor-making work.

All-iron, double-gate valves should be used on pipe lines, and the lines should be assembled with flanges. Long-turn elbows help in avoiding the fouling of pipe lines with lime mud and scale, and in many cases, putting in tees and plugs at points where there is an angle in the line will enable it to be cleaned out easily. In addition to being large enough, a pipe line must not leak and must not plug.

Every caustic-making tank has a pipe and valve for delivering each of the following ingredients to the tank; soda-ash liquor, weak caustic liquor, hot water and steam. There must also be provision made for admitting cold water under pressure to a hose and nozzle, if the lime mud is to be washed out. The basement of the caustic-tank room must be provided with a drain or sewer, to carry away the lime mud.

LIQUOR-ROOM PRACTICE

MAKING THE CAUSTIC LIQUOR

15. Three Systems for Making Liquor.—Three systems for making caustic liquor for soda-pulp cooking have been tried:

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The *first system*, and the one still in use in a large number of soda mills, may be called the **batch system,** because the liquor is made in certain quantities or batches. The operation is necessarily intermittent.

The *second system*, a **continuous system,** employs the caustic-making machinery in such a way that a constant, definite-sized stream of materials is entering at one place, a similar stream of finished caustic is running out at another place, and a current of sludge is flowing away at a third place.

The *third system*, or **filtration system,** is like the first, as regards the boiling of the liquor; but, instead of settling the lime sludge and draining off the clear liquor, the caustic liquor with the lime sludge in it is pumped through filter presses, which allow the clear liquor to pass through, the lime sludge remaining behind, where it is washed free from caustic.

16. What Takes Place when Soda Ash and Lime are Boiled Together.—If a small lump of lime be dropped into a pail containing water, two things will be noticed; *first*, the lime begins to swell and crack and soon breaks down into a powder, which clouds the liquid and covers the bottom of the pail; *second*, the water become warmer, and if sufficient lime be present, the water will actually boil. These two changes indicate that the lime is slaking. The chemical reaction between the lime and the water is expressed by the following equation:

$$CaO + H_2O = CaO_2H_2, \text{ or } Ca(OH)_2$$

It has been proved by careful tests that water dissolves a small fraction of one per cent of its weight of lime. If, now, some of the clear liquid (from which the slaked lime has been settled) be put into a tumbler and a little water, in which some washing soda has been dissolved, be poured into it, the liquid becomes cloudy at once, and the resulting precipitate gradually settles to the bottom of the tumbler as a white powder. This white powder is a different substance from the slaked lime that covered the bottom of the pail; it is heavier, it dissolves less easily in cold water, and it has other different properties. A careful study of it shows that it is like the limestone from which the lime was made, except that it is a powder instead of being solid rock.

The clear liquid in the tumbler, to which the dissolved washing soda was added, is now found to contain caustic soda. The car-

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bon dioxide that was in the soda has changed places with the water in the slaked lime and chalk (calcium carbonate), and caustic soda, or sodium hydrate, is the result. This reaction, which is the cornerstone of liquor making, is expressed by the chemical equation,

$$Ca(OH)_2 + Na_2CO_3 = CaCO_3 + 2NaOH$$

This experiment, which may easily be performed by anyone, shows what takes place in the causticizing tanks when caustic liquor is made. Lime and dissolved soda ash are brought together; some of the lime dissolves, and chalk and caustic result from the reaction with soda ash, Na_2CO_3. More lime keeps dissolving, and the action, which is assisted by heat, goes on until nearly all the lime has become chalk, and most of the soda ash is changed to caustic in mill practice, though 7% to 10% of it remains in the liquor unchanged.

17. The Continuous System.—Fig. 4 shows diagrammatically a patented continuous system for making caustic soda. The lime and carbonate (soda-ash) liquor are running continually from the

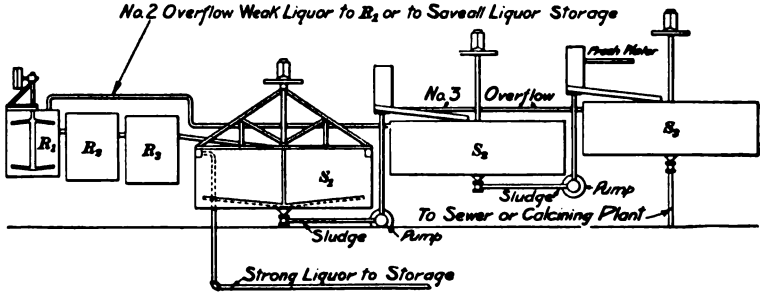

FIG. 4.

recovery system into one of three *causticizing*, or *reaction*, *tanks* and passing through the other two tanks. These reaction tanks R_1, R_2, R_3 are fitted with agitators and steam coils. From the third reaction tank R_3, the mixture of caustic liquor and lime mud flows into one of three very large settling tanks S_1, S_2, S_3. These settling tanks may be 24 feet or more across, and each has a very slow-moving agitator, which permits much settling and, at the same time, keeps the lime mud from becoming hard.

The clear liquor from the top of the first settling tank S_1 overflows to the storage tank for digester liquor, while the thick

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mud in the bottom is pumped into the second settling tank S_2, into which the weak caustic liquor from the top of the third tank S_3 is flowing. The liquor from the top of the second tank is used to make up the proper volume in reaction tank R_1, for slaking lime and diluting digester liquor when necessary. The mud from the second tank is pumped into the third tank, where water is being added. It will be perceived that the mud is traveling through the series of settling tanks in a direction opposite to the travel of the water, which is added at the third tank. This is the *counter-current principle.*

The mud that is discharged from the third settling tank is said to contain less than 1% of the soda that entered the first reaction tank.

FILTERS

18. The Filtration System.—In the **filtration system,** clear caustic liquor may be separated from lime mud by the use of filters, and settling may be avoided. Crude filters, in which the mixture of liquor and mud is run over a bed of sand, have been used for this purpose, but mechanical filters are now employed. These may operate all the time, with a constant discharge of clear liquor and mud, the *continuous filter*, or they may be of the *fill-and-dump type.*

19. The Continuous Filter.—In the **continuous type,** Fig. 5, the filtering medium is a closely-woven wire cloth *a*, which is attached to the outside of a revolving drum *b*, which turns in an open tank *c* that contains the mixture to be filtered. The machine is so constructed that suction helps to deposit the sludge on the surface of the filter as the liquor flows through the wire cloth. One journal bearing is hollow; it carries a suction pipe and a compressed-air pipe, which end in a box that is divided into segments, one large and the other small. The inside end of pipes *e* passes over these segments, and for the greater part of the time, suck out water from between the wooden drum and the wire covered with sludge. For a short part of each revolution, when passing the small segment, air is blown into the pipes *e;* this lifts the sludge from the wire and assists the scraper *s* in removing it. A shower *t* also helps to remove the sludge. Washing is effected by means of a spray of water from pipe *d*, which is outside of the

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drum and operates while the suction is on. An agitator in the bottom of the tank keeps the sludge in suspension. The drum is turned by means of the worm gear *g*.

20. The Fill-and-Dump Type.—The **fill-and-dump type** of filter has several parts: a shell, or chamber, to hold the mixture

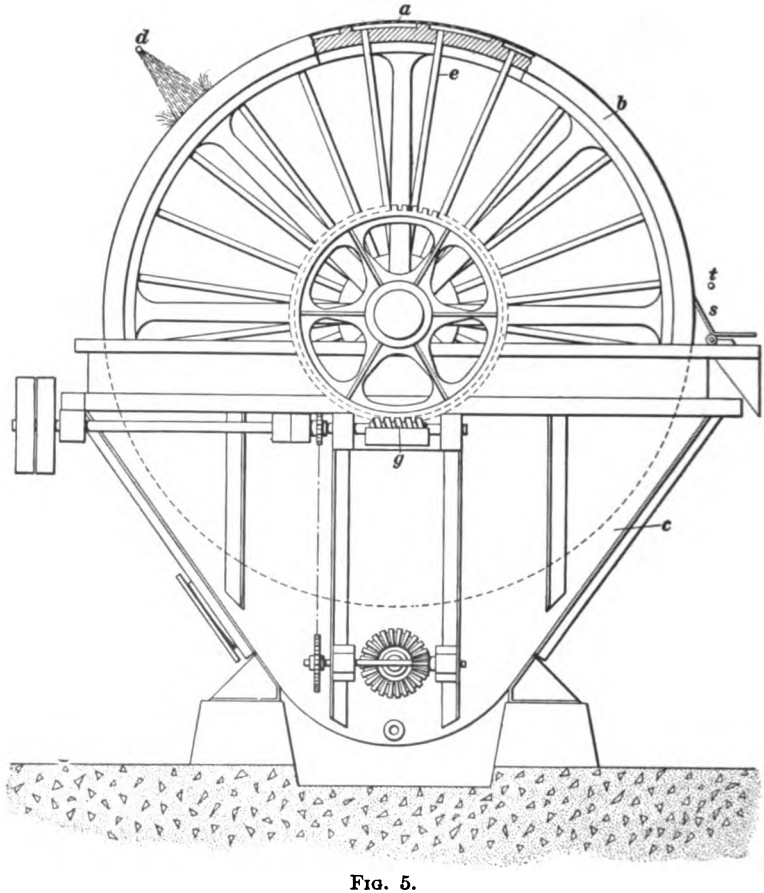

FIG. 5.

to be filtered; inlet and outlet connections; pipes, pumps, etc. Such a filter must be taken apart to dump the cakes, which are formed between corrugated plates covered with filter cloth.

21. The Leaf Type.—In the leaf type of filter, illustrated in Fig. 6, the liquor to be filtered is pumped into the shell. The

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clear liquor passes through the cloth on the leaves, see view (*d*), while the mud builds up a cake on their surface. The frame is removed from the shell, or a portion of the shell is swung off on hinges, and the cake is removed by compressed air or by water.

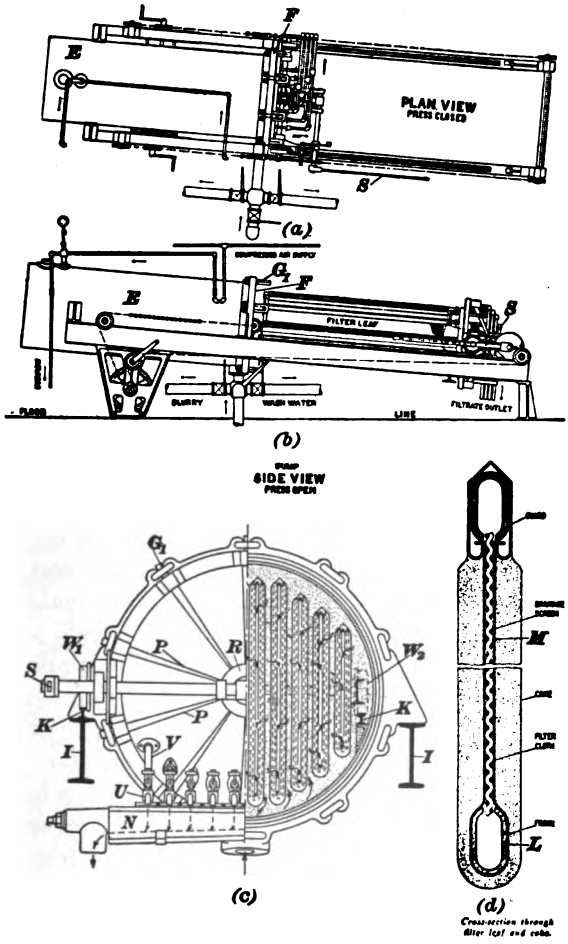

FIG. 6.

The pressure tank, or shell, *E*, is of steel; the front end is made open and is riveted to a heavy cast-iron circular flange, or ring, *F*. The ring is provided with heavy U bolts G_1, which pass through lugs on ring *F*. The U bolts engage the radial locking arms of the head locker, which is described later.

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The front and rear ends of the filter carriage consist of supporting plates for the filter leaves, fastened together with channel irons. The filter carriage is attached to, and has for its front end, the cast-iron head, which is mounted on wheels W_1 and travels on the outer track on top of the I beams *I*. The rear end is mounted on wheels W_2 and travels on rails *K*, see view (*c*), which are supported on brackets inside of the shell. The entire carriage telescopes into the press shell, the head closing the front end of the shell. This movement is accomplished by means of a chain drive, operated either by hand or by a compressed-air motor.

The filter leaves are rectangular in shape, running longitudinally in the press shell, and are made of specially rolled steel pipes *L*, see view (*d*), with a No. 12, 4-mesh, double-crimped, wire screen *M* solidly spot-welded to it. The forward corners of the leaves are connected to the head of the press. All filtrates are expelled here, through the head, and are discharged outside of the head into a trough or filtrate header *N*, see view (*c*). The leaves are, with the exception of the front and rear supporting lugs, entirely enclosed in extra-heavy, special-twill filter bags, which are made with the front end open, and are quickly drawn over the leaves, the open end being then sewed up by hand.

The head-locking mechanism consists of radial lever arms *P*, see view (*c*), and the inner ends are pivoted to a movable collar *R*, which is propelled along a central shaft by a toggle joint. The toggle joint is thrown in or out along the shaft by simply throwing a hand lever *S* in an arc of 180°. As the arms move inward, the outer ends engage in the U bolts, forcing the tongue or head into the groove on the ring and against the gasket, thus insuring a perfect air-tight and water-tight joint. If desired, a hand wheel, with a screw for propelling the locking mechanism, can be substituted for the lever and toggle-joint device just described.

The outlet *V* from each filter leaf passes through the head and ends in a special cock *U*, which empties into a launder or trough *N*. Immediately back of the cocks, the outer nipples are also connected by cross valves into a header or manifold. Both launder and header empty into a suitable box, placed alongside the press, and from whence the liquors are conveyed to their proper destination.

22. Operation of Filter.—Filtration consists usually of a double operation, viz., cake building and cake washing. The

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cake retains a high percentage of valuable salts in soluble form, and these salts should be removed (recovered) as far as possible.

To obtain good results in a pressure filter, the press must be filled rapidly, and it must be full of sludge and under constant pressure during filtration. A centrifugal pump is usually employed.

To obtain a good wash, the cake building must be of even thickness over the entire filter area, and the filter leaves must be entirely submerged. This can be accomplished only by keeping the press shell full of sludge and under constant pressure (30 to 60 lb. per sq. in.) during filtration. Furthermore, to obtain a perfect wash, the cakes must be free from cracks, so the wash water may penetrate every square inch of the cake alike. To prevent cracking of the cake, the press must be quickly emptied of unfiltered sludge, which is sent back to the supply tank and is used in the next operation. The cakes are formed on the outside of the leaves; they must not be allowed to grow together.

Referring to Fig. 6 (*c*), it is seen that the cake is built up, covering the entire leaf, with the filter cloth on the inner side, and the harder part of the cake next the cloth and forming the foundation of the cake. Now since the sludge and the wash water enter the press through the same intake, both filtrate and wash water must travel the same course; namely, from the outer surface of the cake (which is the softer part and is in contact with the liquid), through the cake and the cloth, to the inside of the frame, and out of the press, as indicated by the arrows. Consequently, there is no cause for channels forming, since the wash water enters the softer part of the cake first, which is supported by the harder part, and this uniform cake gives an ideal wash, displacing practically all the liquor before wash water appears at the outlet.

In case the cloths are mechanically clogged, *i.e.*, clogged by dirt or mud, the press is closed and filled with water; the overflow valve is opened, and a steam hose is connected to the filtrate header on the head of the press. The outlet valve is now opened, and steam is allowed to enter the inside of the filter cloths, through the filtrate pipes. The steam will condense until the water is brought to a boil. The ascending steam causes the cloths to vibrate, and all the dirt is immediately removed and dropped to the bottom of the press shell.

In case of chemical obstruction, such as lime incrustation, the operation is repeated as above, with the exception that the press

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is filled with a weak acid solution, which can be pumped into the press through the feed opening, and which, passing through the filter leaves, is carried out through the filtrate openings on the head and back to the storage tank that is used for this purpose. In this manner, the acid solution can be repeatedly passed through the press, as many times as desired, until the cloths are clean and open. In either case, the impurities removed from the cloths may be flushed out through the excess valve and into the sewer.

HANDLING TANKS

23. Mixing Lime and Carbonate Liquor.—The exact manner in which the lime and carbonate are brought together in tanks varies, different mill men having their own ideas regarding this. The carbonate liquor may be pumped in first and the lime thrown into it dry; or the lime may be slaked separately, and the milk of lime run into the liquor, which should be boiling hot. Again, the lime may be slaked in the basket that hangs in the tank. Or, both the carbonate liquor and the lime may be put into the tank at the same time, regardless of which is all in first. Again, a portion of the lime may be slaked in water in the boiling tank or run in from a separate slaking tank, and then the carbonate liquor started, the remainder of the lime being added with the rest of the liquor.

Good settling of the sludge cannot be secured by slaking all the lime in water in the boiling tank, although good causticity may be obtained in this manner. Titration (or the hydrometer, see Art. **27**) will show the strength of the carbonate liquor, and it will indicate the amount of fresh soda ash required to make up for losses; this amount runs from 10% to 18% of the alkali sent to the digesters.

24. Boiling.—When the carbonate liquor (from the leaching of black ash) and the lime are all in the boiling tank, the contents should be nearly boiling, but the tank should not be full. One pound of lime in slaking generates 480 B.t.u., and the carbonate liquor should not be over 165° to 170°F., if the lime is slaked in the same tank; otherwise, the tank may boil over. It ought to be boiled strongly for 15 minutes or longer; then the diluting liquor, which may be second, third, or fourth wash liquor, is pumped in until the tank is nearly full, keeping the liquor

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boiling and stirring it all the time. At this point, the agitator is struck out, and a sample is taken out of the tank with a long-handled dipper, for the laboratory test.

The original strength of the carbonate liquor in terms of carbonate will be known. A second titration will now show how much carbonate remains and how much caustic soda is present. The carbonate converted (original minus final) divided by the original carbonate and multiplied by 100 is the percentage of conversion. If this shows that 90% or more of the soda ash has been changed into caustic, the tank is allowed to settle. If the change has not gone far enough, more lime may be added, and the stirring and boiling are renewed.

Thorough mixing is the important thing, and this may often finish the tank without requiring extra lime.

25. Settling.—Good settling of the lime sludge is necessary: first, because lime in the liquor makes trouble in the cooking and in the bleaching of pulp; second, because any black dirt, or charcoal, or coke that may be in the sludge is likely to go to the digester with it, in which case, it will appear as specks in the finished pulp. The quantity of liquor that can be made in the liquor room depends largely upon the time required for settling.

26. Pumping Off and Washing the Sludge.—Pumping may be begun as soon as the lime mud has settled enough to allow the siphon pipe (P_o, Fig. 2) to be lowered without clouding the clear liquor. The strong and second liquors are pumped off together, to make liquor having a strength of 16°–19°Tw. (say 11°–13° Be.) for the digesters. This allows changes to be made in the strength of the liquor to the digesters. The third liquor, about 3°–5°Tw. (say 2°–3½°Be.), is pumped over, covering the mud from the strong liquor, and forming a new second liquor. The fourth liquor, about 1°Tw. (say 0.7°Be.) or less, is pumped over, covering the sludge from the second liquor and forming a new third liquor. The sludge from the third liquor is now made up with water, forming a new fourth liquor. Stirring and settling are performed each time a sludge is made up with weak liquor.

Three weak liquors, or washes, are usually all that can be taken off one tank; and if the settling and pumping are well done, this last liquor leaves the sludge with between 1% and 3% of the total soda ash put with it into the tank.

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27. Determining the Strength of Caustic Liquor.—For operating purposes, the strength of the caustic liquors is determined by the workman, who uses a hydrometer for this test. This instrument measures the density of the liquid, and is made in many forms, one of which, the Baumé, was described in the Section on *Physics*, Vol. I. A similar hydrometer, but having a different scale, is called a **Twaddell** (abbreviated to Tw.) **hydrometer,** and its scale is called a **Twaddell scale.** This instrument can be used only for measuring the densities of liquids heavier than water. Both the Baumé and Twaddell scales are used in paper mills, but the author of this Section uses the Twaddell hydrometer in his mill, and the Twaddell scale has been employed exclusively throughout this Section. For the benefit of those readers who are accustomed to using the Baumé scale, the nearest practical Baumé equivalents are given in parenthesis, as in the last article. To convert exactly from one scale to the other, use may be made of the table at the end of this volume. Or, one of the following formulas may be used:

Let T = number of degrees Twaddell
B = number of degrees Baumé
S = specific gravity of liquid

$$S = \frac{5T + 1000}{1000} \qquad (1)$$

$$B = \frac{145T}{200 + T} \qquad (2)$$

$$T = \frac{200B}{145 - B} \qquad (3)$$

For example, to find the number of degrees Baumé corresponding to 37°Tw., substitute in formula (2), and $B = \frac{145 \times 37}{200 + 37} = 22.64$°Be., which is the same as the value given in the table at the end of this volume. If it were desired to know the specific gravity at 37°Tw., substitute in formula (1), and $S = \frac{5 \times 37 + 1000}{1000} = 1.185$.

28. Getting Rid of the Lime Mud (Sludge).—In some mills, the final sludge is run directly into a river; in others, it must be used as filling material at some point around the mill premises.

It is possible to dry and calcine this mud, thereby obtaining caustic lime from it. Revolving kilns, similar to those used in

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clinkering cement, have been tried for this purpose, but soda mills have not generally adopted the idea of reclaiming lime in this manner.

29. Storage of Digester Liquor.—Finished caustic liquor is stored in tanks; it is pumped from them to the digesters. Any lime mud that may have been accidentally pumped in from the boiling or settling tanks is allowed to settle out here.

The amount of caustic in the tank at any given depth, measured in inches, is calculated in the laboratory, and the volume is specified that contains the weight of caustic soda that is needed for one digester-full of chips. If electrolytic caustic be used to make up the losses, it may well be put in these storage tanks and thoroughly mixed with the rest of the liquor, by stirring with a current of air or by other means.

The liquor-room foreman is responsible for the operations just described, and he must keep the mill supplied with clear cooking liquor of the right strength.

THE COOKING LIQUOR

30. Amount of Liquor Required.—From 900–1100 gallons, depending on the amount of moisture in the chips, of caustic liquor having a density of 16°–19°Tw. (say 11°–13°Be.) is needed to cook a cord of wood. A mill making 100 tons of soda pulp per day will require from 140,000–180,000 gallons of liquor in 24 hours. Each cord of wood (poplar) requires 800–950 pounds of total soda, expressed as sodium carbonate, but used principally as sodium hydrate; this contains 12%–25% actual sodium hydrate, NaOH, on the weight of dry wood. Not far from 80 tons of soda ash, of which 82%–90% is recovered from black ash, must go into the boiling tanks to make this liquor; 92% of this will be changed to caustic, using for this purpose about 45 tons of lime.

31. Operation of Liquor Room.—When the liquor room is run on the **batch system,** it is operated about as follows: Suppose there are a dozen tanks for boiling and settling the liquor, and a half dozen other tanks for storage. At any time, there should be three tanks of the strongest liquor, testing 28°–30°Tw. (say 18°–19°Be.).

One tank might be making up with a fresh charge of soda ash

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and lime. Two tanks will have second liquors, or first washes, in them, which would test about 8°Tw. (say 5½°Be.). Two tanks will be full of third liquor, or second wash, testing about 3°Tw. (say 2°Be.); and three tanks will contain fourth liquor, or third wash, testing 1°Tw. (say 0.7°Be.). One tank will be empty or washing out. The hydrometer strength of the strong liquor and of the second liquor must be known, since these are to be pumped together, to make up the liquor for the digesters.

To make a test, pour a little of the well-settled liquor into a testing tube made of iron pipe, with a flange on one end to serve as a base. Drop a Twaddell or Baumé hydrometer into this sample of liquor very carefully, and read the density on the scale. The temperature of the liquor must also be known, since the density decreases as the temperature increases, and the hydrometer will sink farther in hot liquor than in one of lower temperature. It is therefore necessary to correct the hydrometer reading to some standard temperature (generally, either 60°F. or 15°C.), which is usually marked on the hydrometer. The safest way is to allow the liquor to cool to the temperature marked on the hydrometer before inserting it in the liquor.

32. Suppose that the strong liquor, which has been settling the longest time, tests 28°Tw. and that the oldest second liquor tests 8°Tw. A table should be prepared by the chemist showing how much of any-strength weak liquor must be mixed (pumped) with a given amount of strong liquor to make the strength wanted for the digester storage. For instance, suppose there are, in this case, 1000 gal. of 28° liquor and that it is desired to dilute it to 19° by using 8° weak liquor; how many gallons of the 8° liquor will be required? Let x = number of gallons of 8° liquor; thus, the total volume after mixing will be $1000 + x$ gallons. Then,

$$1000 \times 28 + x \times 8 = (1000 + x) \times 19,$$

from which, $28000 + 8x = 19000 + 19x,$

or, $11x = 9000,$

and $x = 818+$ gal.

That is, 818 gallons of 8° liquor mixed with 1000 gal. of 28° liquor will give 1818 gal. of 19° liquor. To prove that this is the case, note that the weight of the liquor will be proportional to its volume and to its density; it will be convenient to call the unit of weight the gallon-degree, which is obtained by multiplying one gallon by one degree. Then, the weight of 1000 gal. of 28°

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may be considered to be 1000 gal. × 28° = 28000 gallon-degrees. With this understood, proceed as follows:

$$\begin{aligned} 1000 \text{ gal.} \times 28^\circ &= 28000 \text{ gal.-deg.} \\ 818 \text{ gal.} \times 8^\circ &= 6544 \text{ gal.-deg.} \\ \hline 1818 \text{ gal.} \times x^\circ &= 34544 \text{ gal.-deg.} \end{aligned}$$

Therefore, $x = \dfrac{34544 \text{ gallon-degrees}}{1818 \text{ gallons}} = 19$ degrees, or 19°.

The method of calculation will evidently be the same, no matter what hydrometer scale is used.

These volumes may also be calculated in inches of liquor, provided the depths are measured on the same tank or on tanks of the same diameter. The table can be so made up as to allow for differences in tank diameter. The most accurate method is to use "pounds of caustic per gallon" (or per inch or per cubic foot), as determined by titration. Curves (graphs) may be used instead of a table; and they are often preferable, because a curve represents all values between the highest and lowest values given in the table, and no interpolation is necessary between two values. Also, several curves for different conditions may be drawn on the same chart.

33. A good way to measure liquor from a tank is to have a gauge board standing over, or at the side of, the storage tank, with a tell-tale moving up and down the scale on the board. A chain is attached to the tell-tale, passes over a sheave at the top of the gauge board, and the other end is fastened to a float. As the float falls (or rises), when the level of the liquid falls (or rises), the end of the chain to which it is attached goes with it, and this causes the tell-tale to rise (or fall). If the scale of the gauge board be divided in inches, the movement of the tell-tale will show the number of inches of liquor being pumped into or taken out of the tank; and if the tank is cylindrical and its diameter is known, the corresponding volume is readily found. Instead of inches, the scale might be so divided as to indicate gallons or cubic feet. As much of the strong liquor should be pumped out, by gradually lowering the siphon pipe, as can be removed without pumping mud.

34. If the second liquor does not hold out, use a little third-degree liquor to finish, being careful to change the proportion according to the table. If there is too much second liquor, pump

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what is left into the next tank, which is to be boiled up with soda ash and lime.

If a supply of caustic from the electrolytic plant is on hand, it is a good plan to run some of it into each storage tank, stirring thoroughly with compressed air or by other means. This insures that the electrolytic caustic is evenly distributed, which is particularly necessary if it contains salt. Salt makes the hydrometer read higher than it would if caustic were the only chemical added in the liquor; in fact, 1% of salt will raise the hydrometer reading 1°Be. or 1.4°Tw. It is therefore safer to depend on the chemist's tests than on hydrometer readings, although the hydrometer is generally used for testing and mixing. The final liquor should be tested chemically for its caustic strength.

35. Losses.—Losses and waste of soda liquor and of lime often result from (*a*) pure carelessness, such as leaving a valve open too long and letting the liquor run into the drain, or by wrongly setting in a wash-out plug and letting a tank empty through this hole. (*b*) By misjudgment, such as having the black-ash liquor too hot when the lime is put in, thus causing the tank to boil over on account of the heat of the slaking lime. (*c*) By failure thoroughly to draw off the liquor from the lime mud; this means greater loss of soda in the mud. (*d*) Lastly, and perhaps oftenest, losses occur from leaks at pipe joints and flanges, tank seams and rivets, valve stems, gates, pump packings, etc. The careful and faithful liquor-room foreman will find these leaks and have them stopped before any considerable losses occur.

In addition to the foregoing, some soda is certain to get away with the lime sludge, and some leakage and spattering will occur in even the best regulated liquor room; but such losses must not exceed from 1% to 3% of the total alkali entering the room. The larger the tank capacity is, in proportion to the soda ash handled, the more time there will be for good settling and the smaller the loss with the lime mud. While all the soda *could* be washed out of the sludge, it would cost more to handle the great volume of liquor than the recovered chemical would be worth.

The lime sludge may be filter pressed, dried, and used for any purpose for which ground limestone can be used, as in farming, for instance. Whiting can be prepared from it. The powder may be calcined in a revolving kiln and quicklime recovered.

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36. Hazards.—The special risks to be avoided in liquor-room work are: Do not allow hot caustic to spatter into your face; it is very injurious to the membranes and will ruin the eye if it enters it. Avoid inhaling lime dust; wear a respirator when working around dry lime. Men have been known to stumble and fall into a tank of caustic—nothing was recovered but a few coins and teeth. Be careful!

QUESTIONS AND EXAMPLES

(1) From the description given of the process, make a plan of a liquor room to operate on the batch system. Begin with the storage of chemicals and end with liquor storage.

(2) (*a*) What is the purpose of the soda process? (*b*) Name the principal raw materials used in the soda-pulp mill.

(3) What chemical reaction takes place (*a*) when lime is slaked? (*b*) when soda ash is causticized?

(4) State the principal differences between the batch system and the continuous system of liquor making.

(5) Name the principal duties of the liquor-room foreman.

(6) How much water, lime, and soda ash is required per day for a mill making 100 tons of pulp?

(7) How much weak liquor of 10°Tw., must be added to 100 gal. of 26° liquor to make a cooking liquor of 19°Tw.? *Ans.* 77.8 gal.

(8) How can losses in the liquor room be minimized?

THE COOKING PROCESS IN A SODA MILL

THE DIGESTER HOUSE

37. The Digesters.—The dissolving of the non-fibrous part of the wood by means of water, caustic soda, and heat takes place in vessels called **digesters.** The part of the mill in which these digesters are situated is the **digester house** or **digester room.**

Both the quality and quantity of pulp that a mill can produce depend in large degree upon the proper running of the digesters. Pulp that is well cooked is more than half made; and while it is possible to spoil it in later operations, it is much easier to avoid this than to make good pulp out of poorly cooked material. The digester house should always be arranged as conveniently as possible.

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38. Arrangement of Digester House.—The digester house receives chips from the wood-preparing room, with which it is connected by some sort of conveyor. It receives steam from the boiler house through a steam main, and it gets caustic liquor from the liquor room by piping. The cooked pulp is discharged from the digester house into the washing room, and goes through other processes preparatory to shipping. The cooking liquor that drains off is conducted to storage tanks, from which it goes to the evaporators.

In soda mills, the digester house is always near the washing room, but the chipper room and liquor room may be at some distance from it. The size of the digester house will, of course, depend on the amount of pulp to be cooked in it and, also, upon the size of the digesters and their design. Modern practice favors tall digester houses, with roomy chip bins at the top and above the working floor; large capacity digesters, with blow valve in the center of the bottom; and blow piping passing up to blow pits above the washing tanks.

It is the general custom to operate the steam valves and blow valves from the main working floor. An elevator should be provided for passing from the working floor to the basement, for inspection of and operation of the blow valves or for doing other work.

THE DIGESTERS

39. Riveted and Welded Digesters.—Digesters for cooking wood by the soda process have always had the shape of a cylinder, with ends either rounded or cone shaped or having some other convex form, and having a diameter equal to one-fifth to one-third the length (height) of the cylinder. In the early days of pulp making, the digesters were small, and the iron plates of which they were made were riveted together. No lining has ever been needed for the digesters, as the caustic and black liquor do not seriously attack the metal. However, trouble has always resulted from leaks in riveted soda digesters, and the fine spray of black liquor that escapes from the leaks often makes the digester house a very uncomfortable place. In more recent times, seamless vessels have been made by welding together mild steel plates; very satisfactory digesters have been pro-

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duced in this way, some having a diameter as large as 10 feet and a height of nearly 50 feet. A seamless digester is preeminently adapted to the soda process rather than a lapped joint and riveted digester; because, although the solution of caustic soda that is used for digesting the wood does not attack steel or iron greatly, it, nevertheless, has great avidity for oxide of iron or iron rust. In a lapped seam and riveted digester the sheets of steel used are coated with a thin black oxide, which really separates the two sheets in the lapped seam. The caustic soda quickly eats out this oxide and therefore the seams quite readily leak. In a steam boiler, water does not eat out the oxide; therefore, such a container is tight against steam pressure, but not against hot caustic soda solution. In cases where still larger digesters were desired, the manufacturers went back to the riveted type. The only way by which these large ,riveted vessels can be kept free from leaks is by electric welding of all seams and rivet heads after the digester is in place in the mill. Soda digesters that hold between 14 and 15 cords of wood are in use, and will cook about 6–8 tons of pulp per charge.

The type of digester that has found favor in most soda mills is that in which the cylinder stands upright on one end; it is supported by a cast-iron ring, fitting the outer part of the convex bottom, and rests upon brick or steel supports. Supporting brackets resting on cast-iron columns may be riveted directly to the shell. At the upper end is the opening through which the chips are charged into the digester from the chip bin above it; at the lower end is the blow valve for discharging the cooked pulp to the blow pit. The shell of the digester is made thick around all openings, to form a heavy ring or boss; these bosses are faced off smooth, to allow flanges to be bolted to them for attaching covers, pipes, and valves.

The working floor of the digester house is near the top of the digester; the digester operator, or cook, does most of his work on this floor.

40. Description of Digester.—The **upright, or vertical, digester** *A*, Fig. 7, has a false bottom *N* shaped like an inverted cone; it is made of sections of perforated steel plate, bolted together and tapering to the discharge hole *F* in the center of the bottom. There is an opening for the steam pipe *T* in the side or bottom of the digester, below where the false bottom joins the digester, and there may be another opening for the circulating pipe. The

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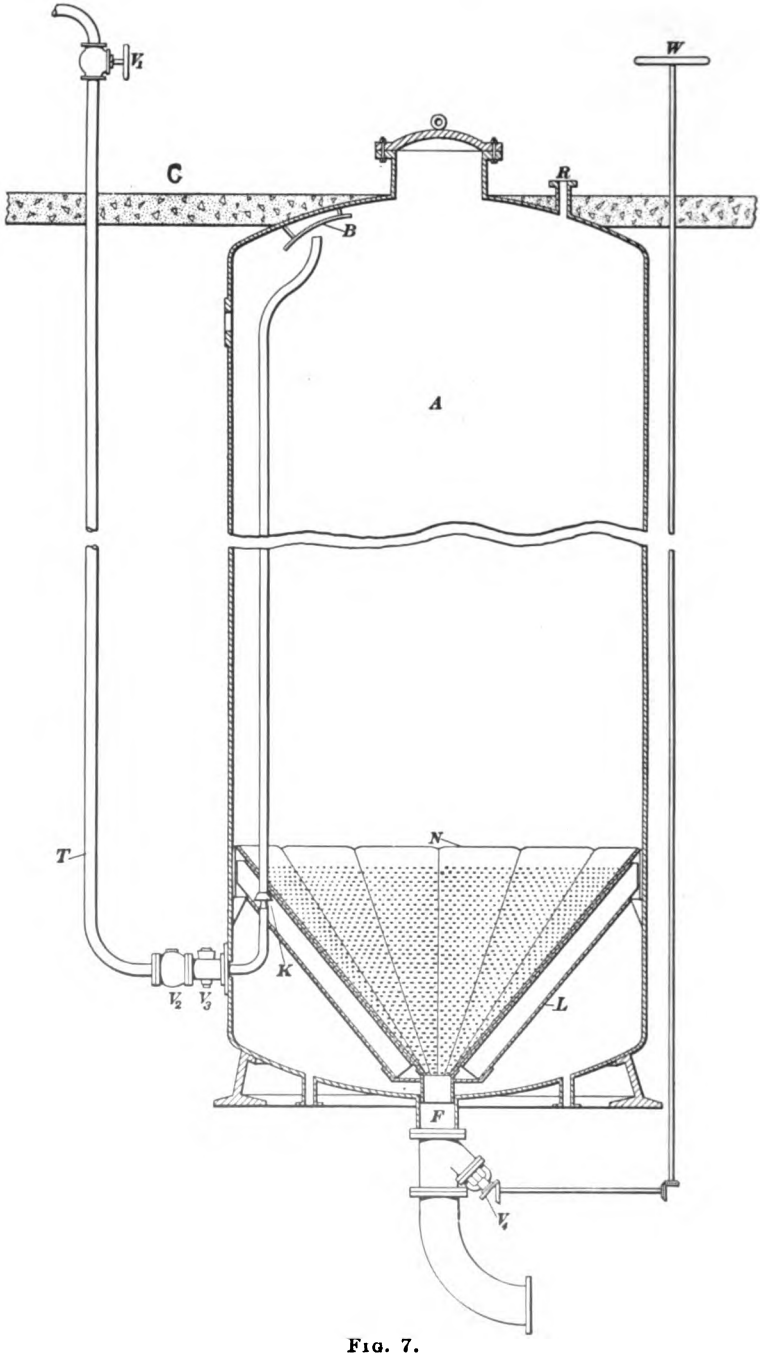

Fig. 7.

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design of this digester, with its lower cone L, is largely a matter of construction. The steam is controlled by globe valve V_1, check valve V_2, and plug valve V_3. The relief line and valve connect with the digester at R. V_4 is the blow valve, operated by hand wheel W. C is the working-floor level.

The manhole end of the digester has been constructed in several different ways, three of which are shown in Fig. 8. In Fig. 8 (a), a cast-iron throat piece 1 is bolted to the boss 2 around the manhole; the joint is made tight by means of a sheet-lead

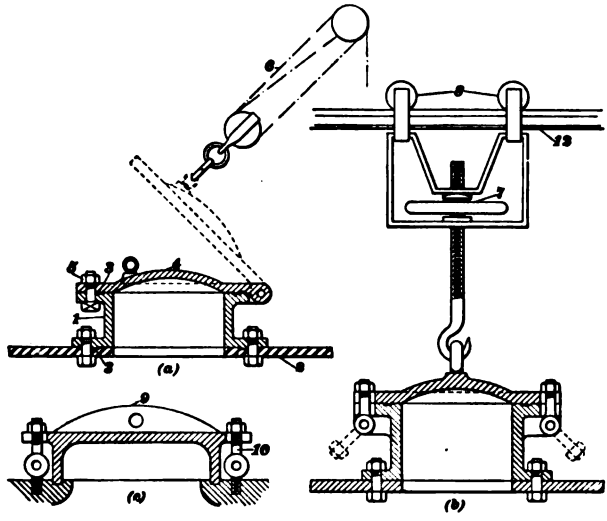

FIG. 8.

gasket 3, which is placed in a groove in the boss, into which fits a projection on the flange of the throat. The digester cover, or head, 4 is bolted to the throat piece by heavy bolts and nuts 5; the bolts fit into slots in the rim of the cover and into similar slots in the flange of the throat casting. The bolt heads are made square, to keep the bolts from turning when the nuts are tightened up. This style of digester head is hinged to the throat casting, and the bolts are removed when the head is to be raised. The joint between the head and throat is kept tight by a lead packing 3 similar to that between the throat and the digester boss. A light chain block 6 swings the head on its hinges.

The style of top shown in (b), Fig. 8, differs from that shown in (a), in that there is no hinge on the head, the head bolts being

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hinged to the throat piece by means of lugs and pins. The head is lifted off the throat piece by the hand-wheel and screw device 7, which runs along a rail 12 over the digester on small flanged wheels 8.

A handier rig is shown in (*c*), Fig. 8. Here a single steel casting 9 constitutes both throat piece and cover, and it is necessary to keep only one joint tight. This rig is handled in the same manner as in (*b*). The cover bolts 10 are jointed; one end screws into the boss on the digester, and the other end swings into the slot in the rim of the cover casting.

41. Horizontal digesters, which revolve slowly while the wood is cooking, have been used in a few soda mills. The following is a description, condensed from E. Sutermeister, of this type of digester.

"Rotary riveted digesters in American practice are generally about 20–24 feet long and 7 feet in diameter; larger ones have been constructed, but have been very hard to keep tight, because the strains they set up as they rotate tend to start their seams. They are filled with chips through manholes in the sides; and, in order to get in as great a charge as possible, some form of tamping device is necessary. A steel cone, fixed (apex down) on the end of a shaft that is alternately lifted and dropped by an eccentric, gives excellent results in packing in the chips. Steam for heating the charge generally enters the rotary through one of the two trunnions; the trunnion at the other end of the rotary is piped up, so air or steam can be relieved through it. After the cook is completed, the relief line is opened and the pressure reduced. The heads are then removed, and the charge is emptied into the wash pits below, by the simple expedient of revolving the rotary."

For an illustration of the horizontal rotary digester, see Section on *Preparation of Rags and Other Fibers*, Vol. IV.

Double-shell digesters have been used for cooking wood by the soda process. The steam for heating the charge is contained in the space between the two shells. This type has not proved successful, by reason of leakage and waste of steam.

42. Ways of Heating and Circulating Contents of Digester.— There are several ways by which the chips and caustic-soda liquor may be heated in a soda digester. By the **direct heating method,** the steam may be led directly to the lower part of the digester; this causes the cooking to begin where the steam is admitted, and

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the boiling liquor rises through the mass in the digester, which sets up a circulation that finally brings the whole up to full cooking temperature.

By the method of **injector circulation,** Fig. 7, the steam may be led through the shell of the digester and into a simple form of injector, *K* situated under the perforated bottom. A pipe leads from the top of the injector and up along the side of the digester. The pipe is supported by lugs to a point near the top of the digester, where a curved deflecting plate or sprinkler, *B* is fastened in such a position as to spread over the chips the liquor that is discharged through the pipe. Several such injectors may be placed in a digester. In such an arrangement, the cooking begins at the top of the digester.

Injector circulation gives good results in digesters of moderate height. An injector is simply a steam nozzle that discharges upward into a pipe that is open at the bottom to the liquor. The velocity of the steam keeps the liquor circulating and, incidentally, heats it at the same time.

PUMP CIRCULATION

43. Distributing the Heat in a Digester.—The heat can be quickly distributed to all parts of the digester by using a pump for circulation, together with direct heating; such a system is illustrated in Fig. 9. Centrifugal pumps have been bolted to a flanged neck on the side of the lower part of the digester, below the false bottom; they may also be connected to the digester by means of piping. Reciprocating steam pumps may be used for the same purpose. The liquor that is drawn out by the pump is returned at the top of the digester. Any one or all three of these methods may, of course, be used on the same digester.

In Fig. 9, steam is admitted through pipe *D*, valve *V*, and perforated coil *K*. *E* is the relief connection, *C* is the cover, and the digester is charged through the throat *B*. The liquor drains through the perforated bottom *N* and flows to pump *H*, which feeds it through pipe *T*, to be distributed over the chips. The charge is blown out through connection *F*, blow valve *G*, and blow pipe *P*.

Mention may also be made of the coil method of heating, which has been tried in some mills; however, it had to be abandoned,

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because of mechanical difficulties. In this method, the steam was not allowed to enter the charge, but passed through coils of pipe, which were placed around the inside of the digester.

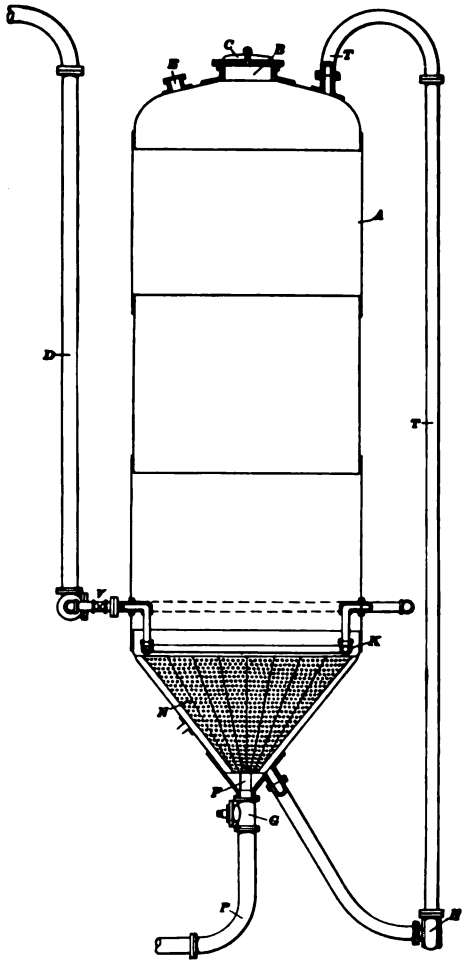

FIG. 9.

44. Indirect Heating.—In the process using a system of indirect heating, illustrated in Fig. 10, a pump is used for the circulating, but the steam for heating is not blown directly into the digester *D*. Instead, the steam is led to a heater *A* outside of the digester; and the circulating liquor from the pump passes

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through this heater, which is so designed that the steam is on one side of and the liquor is on the other side of a series of tubes *C*. The condensed steam is fed back to the boilers or wash-water tanks by the condensate pump *G*, instead of going into the digester; thus the liquor that returns to the digester is not weakened by the addition of condensed steam.

45. Preventing Waste of Heat from the Digester.—Welded digesters can easily be covered with material that will reduce the loss of heat by radiation; asbestos felt, magnesia coverings, or a combination of these may be used. In many cases, this heat-saving substance is put on with a trowel, and is held in place by coarse-mesh wire fabric, hung from a metal ring around the top of the digester. Much heat is saved in this way and less condensation is found in the digester, to dilute the liquor.

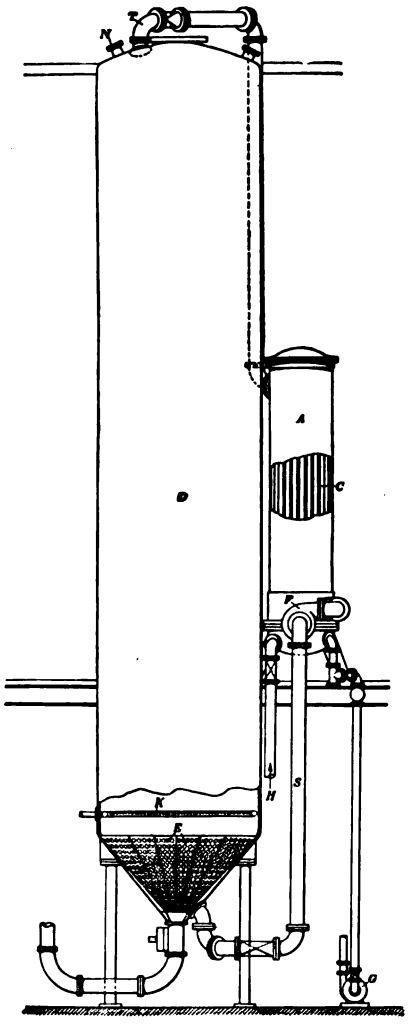

FIG. 10.

DIGESTER-HOUSE DETAILS

46. Blow Pits.—The **blow pit,** or **blow tank,** is a vessel large enough to hold easily the contents of a digester, and a line of blow-piping connects one or more digesters to it. Blow pits are generally placed at a considerable elevation above the washing tanks, in order that the pulp, or stock, may be taken down into the tanks by gravity.

The blow pit separates the steam, which is set free when the

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digester is blown, from the stock and liquor. This is a very important function, since more than 2000 cu. ft. (about 85 lb.) of steam escapes into the air for each cord of wood in the digester charge.

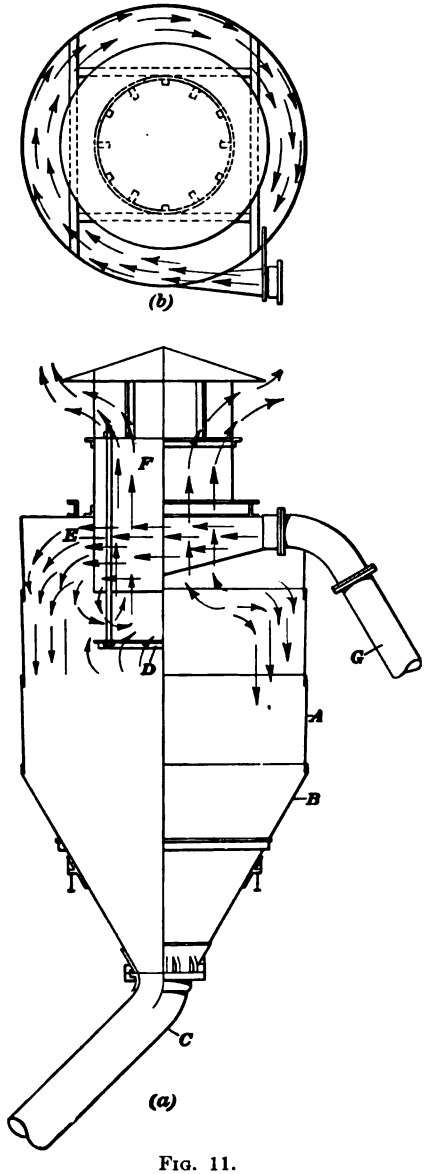

FIG. 11.

The roofs of some mill buildings in the vicinity of the digester house often present a very unsightly appearance, due to the black pulp that was thrown out of the "vomit" pipe above the blow pit with the steam, and which rained down on them. The clothes of passers-by sometimes suffer from the same cause. At present, with a well-designed blow pit, all the steam escapes without any waste of pulp or black liquor. Sutermeister describes a well-planned blow pit; Fig. 11 shows this in part-sectional elevation at (*a*) and in plan at (*b*). The stock, coming through pipe *G* from the digester, is given a whirling motion, drops into the hopper *B*, and is delivered by pipe *C* to the wash room. Steam and gases pass the baffle plate *D*, which is supported by bolts *E*, and out through the throat *F*.

47. Valves.—Much of the success of running a digester house depends on the valves or cocks by means of which the liquor and steam are turned into

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the digester and kept there or are discharged when required; these must be rugged and reliable. On the steam line, there should be a throttle valve V_1, Fig. 7, at a convenient distance (height) from the working floor C. Nearer the point where the steam enters the digesters, there should be a check valve V_2, to keep liquor from leaving the digester (if the steam pressure falls), and a plug cock V_3 for use when repairs are to be made to either check valve or throttle valve while pressure is on the digester; this last cock is also closed down while steam is being taken out of the line.

An all-iron globe valve, with lead fitted disk, makes a good throttle valve. The check valve and plug cock are of cast iron. On the relief line R, which leads from the top of the digester to the blow pit, there is a relief valve; a double-gate all-iron valve is used here. At the bottom of the digester, and connecting it to the blow piping, is the blow valve V_4. This has been made in various styles, an excellent form being an all-iron Y valve, with a lead fitted disk that can be easily renewed. The valve stem has a screw thread, and the valve is run in and out by means of a pair of bevel gears that are connected by shafting and other gears to the hand wheel W, which is on the working floor of the digester house. Some mills prefer a plug cock, as shown at G, Fig. 9.

The first thing that the cook does when coming on duty is to look over the records and valves. The steam valve should be opened wide enough on the digesters that are cooking to maintain the necessary temperature and pressure. The relief valves should be shut, unless the digester is being relieved. The liquor valves should be shut on all digesters, except on one that may be filling. A careful inspection of these valves may save a great deal of trouble, since closed or partly closed steam valves on digesters that are supposed to be cooking mean lost time and perhaps bad cooks. Open relief valves that should be shut mean waste of steam, and open liquor valves lead to no end of trouble and confusion.

48. Gauges.—A steam pressure gauge, similar to those used on steam boilers, is connected to the digester shell or to one of the pipes leading from it; it is a very useful guide to the cook in handling his digesters. Both the pressure and temperature gauges may be of the **indicating type,** an indicator (pointer) showing the pressure or temperature; or they may be of the

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recording type, in which case, an inked line is drawn on a sheet of paper, by means of which a permanent record is made and the reading can be taken for any moment of the day. The pointer, which holds a pen that traces the inked line, moves in accordance with the variations in temperature or pressure, while the sheet turns around once in 24 hours, being revolved regularly by clock work. A new sheet (chart) is inserted in the instrument every day.

49. Thermometers.—The pressure gauge shows the cook what the pressure is inside his digester, but it does not tell him how hot it is there. Since pressure may be caused by agencies other than heat (as gas or hydraulic pressure) and since only heat does the cooking, the pressure gauge is not sufficient to control the digester properly. To tell how hot the stock is at any time, a thermometer is needed. A steel socket is welded into the digester shell at a point away from the circulating pipe; this is filled with a heavy oil, and the thermometer bulb is screwed into it, the bulb being in the oil. In the case of a recording thermometer, the bulb is connected by flexible tubing to a device that moves a pen over a chart and makes a permanent record of the temperature at each instant of the day. Such a chart is shown in Fig. 12, and will be discussed later. A table at the end of this volume shows what the temperature should be for various pressures.

As soon as the cook arrives, he should read the steam gauges and thermometer charts, and compare their readings with the record his tour partner has left. He may find that a digester has been reported as *on* at the wrong time, that some digester is not coming up right, etc., etc. The curves on the chart show what *has* happened, and they indicate what is to be done.

DIGESTER OPERATION

50. Results Sought.—The results that the soda-mill cook is trying to obtain are these: 1, well-cooked pulp; 2, a clean blow, *i.e.*, a perfect discharge of the pulp when the cooking is finished; 3, a large yield of pulp for each cord of wood put into the digester; 4, a large amount of pulp for each digester blown; 5, pulp that will wash quickly and easily in the washing tanks; 6, enough pulp each day to keep the mill going to full capacity; 7, to waste the least amount of liquor and steam.

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To obtain these results, the cook must pay careful attention to the following: 1, the kind of wood he is cooking and the size of the chips; 2, the amount of water (moisture) in the wood; 3, the weight of caustic soda that he puts into the digester (this is another way of expressing the strength and causticity of the liquor, as shown by the hydrometer or by analysis); 4, the volume of liquor that he uses; 5, the pressure of the steam; 6, the time the digester is held at full pressure; 7, the readings of the thermometer; and several other details.

Any one of the above mentioned details may change from normal from time to time, either with or without his permission; but, in order to make pulp that is always alike, the soda-mill cook must alter the way he handles his digesters, to fit other changes that he cannot prevent.

Some kinds of chips may have a preliminary treatment, to dissolve some soluble matters from them before cooking. For instance, chestnut chips may be soaked in hot water, to dissolve tanning materials, and hard pine may be treated with some solvent, to remove resin.

51. Filling the Digester.—Starting with an empty digester, the first step is to fill it with a charge of chips and caustic-soda liquor. The liquor may be pumped in or it may be run in from a tank above the digester. The quantity is varied in accordance with the amount of water in the wood and with the strength of the liquor. A cord of poplar wood that has been soaking in the river before chipping, contains the equivalent of about 200 gal. more liquor than ordinary wood that has been well seasoned in the air.

Liquor may be introduced first, and the chip gate may be opened a minute or so later. Both chips and liquor are run in together until the digester is nearly full of chips. The steam valve is opened a little as soon as the injector (or coil) is well covered, and the liquor is circulated as rapidly as possible without blowing steam into the room. The object of this proceeding is to wet thoroughly the chips that are above the level of the liquor and to soften all the chips, so that they will settle and allow more chips to run into the digester. A long-handled paddle may be used to push the chips from the manhole and fill up the space in the upper part of the digester. Thorough work at this time pays well in large blows. Packing can be overdone, however, and it should not be too tight.

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The top of the digester is next swept clean with a broom or with a jet of compressed air, and the head is put in place and bolted on. The steam value is now turned on full, and the time is noted on the record.

52. There is more to filling a digester than is apparent at first thought. While a lot of wood should be put into the digester, in order to get a big blow, it is also requisite that the digester *blow clean*, and both these objects cannot always be obtained simultaneously. A digester may be packed so full that it will not blow clean, which makes it necessary for it to go on second pressure (require a second blowing); this is especially true of heavy wood, such as birch. The aim is to have a certain amount of liquid in the digester after all the steam has condensed in it that will do so; it is probable that if more than the right weight of dry wood is put in, this liquor will not be sufficient to make sure of a clean blow. Some mills are able to obtain larger blows when they are using water-soaked wood direct from the river than when they are using dry wood. There must be enough liquid to carry the pulp out, and sufficient room must be allowed for the steam to condense. A big yield from wet wood may be due to: 1, better packing of chips; 2, cleaner blowing (less pulp left in the digester); 3, less solution of cellulose; possibly, to all three causes combined.

When cooking poplar, about 200 gal. less of proportionately stronger liquor per cord of thoroughly wet wood is required than is needed for air-dried wood. The weight of caustic used should be somewhat higher, and the strength of the liquor should be raised, in order to avoid over-crowding the digester with liquor that will be lost when the digester is relieved. The thermometer and steam gauge will give considerable information regarding this.

53. Steaming the Digester.—Refer to Fig. 12, which is a reproduction of an actual temperature chart of a day's run when everything was working right. The chart was taken on an 8-ft. by 30-ft. digester having injector circulation; it shows curves for two complete cooks and for parts of two others. The chart was put on the recorder at 3:30 p.m., as indicated by the point *a*. Curve *A*, from *a* to *c*, shows how the temperature ran during the last part of the cook in progress when the chart was changed; curve *B*, from *c* to *h*, shows how it ran during an entire cook; curve *C*, from *h* to *r*, shows how it ran for another entire

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cook; and curve *D*, from *s* to *u*, shows how it ran for the first half of the fourth cook. The chart here shown is about one-third the actual size.

Considering curve *C*, at point *h*, the straight line to point *i* shows that the temperature is falling fast from about 275°F., on account of putting cold chips into the hot digester. From *i* to *j*, the temperature rises to about 170°, as a result of the hot

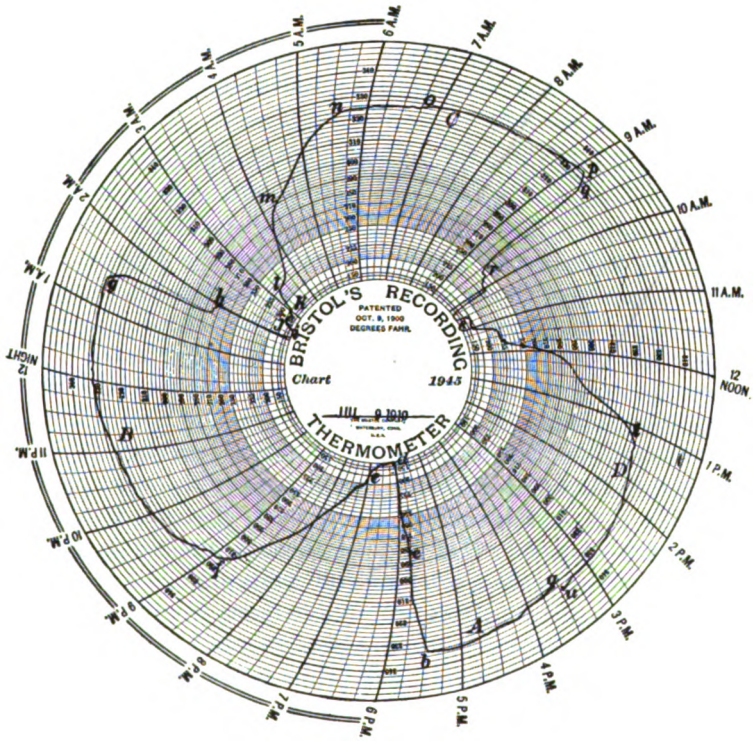

FIG. 12.

liquor, which has soon covered the thermometer bulb. The digester is put *on* (steaming begins) at point *k*, and the temperature increases to 225° at *l*, when the curve mounts more slowly for about half an hour; it then rises rapidly to point *m*, where its rise is again slowed down until point *n* is reached; from this point, the rise in temperature is slower until the cook is finished. A rapid rise in pressure (as shown by the pressure gauge at the corresponding times) without a corresponding rise in temperature,

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would indicate a fictitious, or gas pressure, and the relief valve should be opened to correct this.

The digester is relieved at point *o* and again at *p*, preparatory to blowing. At point *q*, the digester is blown, and the temperature rapidly falls to 250° at point *r*.

Something may also be learned regarding how the digester is working by putting one end of a wooden stick or iron rod on the head of the digester and placing the ear close to the other end. The sound of a strong, steady discharge of the liquor against the sprinkler plate is heard for the first half hour; this gradually dies down to a fainter, but regular and distinct, throbbing sound, as the cooking goes on.

54. The charge heats up gradually, as shown by the chart, and the steam pressure inside the digester rises and shows on the steam-pressure gauge. The action of the steam in the injector causes the liquor below the false bottom of the digester to rise to the upper part above the chips, and at the same time, the steam heats the liquor. The upper layers of chips are thus cooked before the layers below them. The chips in the bottom of the digester are also cooked before those in the main body, between the bottom and top, because of the steam having been let in at the bottom. As long as the injector is working, there is a movement of liquor downward from above and through the chips, and there is a movement upward through the circulating pipe. The heat is spread in this manner through the whole digester, and the cooking process is completed uniformly.

The time required is from two to five hours from the time that full pressure is reached, when aspen (poplar) is being cooked. With spruce and hard wood, more time is necessary. By using pump circulation, the time of cooking can be lessened, since the rate at which liquor is thrown up with an injector grows less as the pressure in the digester increases. Other details of running the digesters will be different when the method of heating differs from that here outlined; these details are influenced by, and must be determined by, local conditions, such as quality of pulp, character of wood, radiation losses, etc.

55. Relieving the Digester.—When the digester head is put on, there is some air in the spaces between the chips above the liquor level and, also, in the pores of the chips. The air and any gases (acetone and turpentine are volatile with steam) that are

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formed during the early part of the cook must be removed from the digester, or the circulation may stop, which causes the lower part of the digester to stop heating, although the gauge shows full pressure. To remove the air, the relief valve is opened, and the air (and gas) passes through the relief line into the blow pit. The amount of relieving that must be effected varies according to circumstances. As before mentioned, the thermometer chart will often show when the digester should be relieved.

If through mistake or bad judgment, too much liquor has been put into the digester, it may be blown out through the relief valve, and the circulation, which has stopped, can generally be started again by the opening of the relief valve. The cooking process is controlled mainly by the relief valve, and some mill men think it is a good plan to have a slight constant relief, by boring a $\frac{1}{8}$-inch hole in the plug of the relief cock.

56. Blowing the Digester.—When the digester has been at full temperature for the right length of time, it must be blown, or discharged, into the blow pit. Before doing this, the piping between the blow valve and the blow pit should be drained of any liquor that may be in it and heated up by blowing steam through it; this is done by opening a drip cock at the lowest point in the line and then blowing steam through the line. This precaution prevents damage to the pipes, caused by the heat in the stock coming on suddenly and creating "water hammer." The main valve should be shut and the relief valve opened from 15 to 20 minutes before blowing, thus relieving the digester until the gauge shows a drop of 25 lb. Relieving at this point helps to effect a clean blow. The blow valve is opened as quickly as possible, and the mass of pulp and black liquor is blown out of the digester into the blow pit. In order to start the blow, it is sometimes necessary to loosen up the pulp in the cone just above the blow valve, by blowing in a sharp blast of steam at this point.

57. Preparing Digester for Next Cook.—As soon as the digester is blown and when the steam gauge shows no pressure, the cover nuts are slacked off, the bolts swung back, and the digester head is hoisted off. The blow-valve disk and seat are scraped and washed off, and the valve is closed. It is watched a few seconds, to see if there is any leak, and the valve cover is clamped on. A sounder, made of an old washer or other piece of metal and fastened to a cord, is dropped slowly into the digester, and is swung

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back and forth like a pendulum, to find out if the digester is empty; or an electric bulb is dropped in on a leader, for the same purpose. A small amount of pulp may be left in the digester, and chips and liquor for the next charge are put in at once. But, if much pulp remain in the digester, enough black liquor is pumped in to cover the pulp, and the digester is steamed and blown again.

58. The foregoing directions for handling soda digesters apply particularly to those in which injector circulation is used. When a circulating pump is employed, the arrangement is usually the same as is shown in Fig. 9. The circulating pump is outside the digester shell, and there is thus a greater tendency to cool the liquor, which necessitates the use of more steam, proportionately. The system for heating the liquor outside of the digester is described more fully in the Section on *Sulphate Pulp*.

59. Digester Troubles.—Too much or not enough liquor may be put in the digester, though there is little excuse for this. The steam pressure may drop during the cook; in which case, shut off the steam, in order that liquor may not be forced out of the digester in case the check valve is not tight. The circulating pipe may become loose, come apart at the flanges, or plug up. The injector may become loose and get out of place. The sprinkler plate may come off. Pulp may fill up the space between the true and the false bottoms of the digester. The causticity of the liquor may be too low. The circulating pump may slow down; etc., etc.

60. Where there is a sufficient quantity of caustic soda in the digester, but not a sufficient volume of liquid, it is the practice in some mills to put in black liquor to make up the volume; this helps circulation and keeps up the strength of the black liquor that is sent to the evaporators. Some mill men think that the stock bleaches harder (requires more bleach) when black liquor is used in the digester, but there is a difference of opinion regarding this.

Several substances other than soda ash have been used in making cooking liquor, in attempts to change the quality or quantity of the pulp. A few mills have adopted the use of sulphur in small quantities, believing that the yield is thereby increased; this introduces sodium sulphide, Na_2S, into the liquor, and the sulphide has a milder action on the wood fiber. Salt cake.

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Na_2SO_4, when added to the rotary incinerator, gives about the same result; the process then becomes virtually a sulphate process. A more recent suggestion is the use of mercury, but no mill results are available for determining the efficiency of this method.

61. Experimental Digesters.—The results obtained with small digesters are helpful in operating the larger digesters. But, it must be remembered that in the larger digesters, there is one important difference: the chips in the different sections of the digester do not all receive the same treatment. Thus, the top layer is cooked first with strong liquor that contains most of the caustic soda, and the pulp is then subjected to the action of a gradually weakening liquor for the remainder of the cook. The lower layers, on the contrary, while soaked with liquor of the original strength, receive their final cooking through the action of much weaker liquor, the caustic in which has been largely used up. Each large digester, then, contains portions of pulp that have been cooked for different lengths of time at full temperature and that have been separated from the non-fibrous part of the wood by liquor of different composition.

In the small, experimental digesters, the chips are all so near together that they all receive more nearly the same treatment. Since they are heated externally, there is no variation in the volume and strength of the cooking liquor, due to condensation of steam.

QUESTIONS

(1) Describe briefly the principal types of digesters.
(2) Why it is necessary to circulate digester liquor? how is it done?
(3) Explain an indirect cooking system.
(4) For what is the blow pit used? why is it sometimes a source of loss?
(5) What metal is generally used in the soda mill?
(6) Name some advantages in using recording gauges and thermometers.
(7) Explain the effect of wetness of wood on the cooking of pulp.
(8) What is meant by relieving a digester? why is it necessary?

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WASHING PULP AND RECLAIMING CHEMICALS

WASHING SODA PULP

82. Purpose of Washing.—The black mixture of pulp and of liquor, which contains the dissolved non-fibrous part of the wood, must be separated into clean pulp and black liquor as the next step in the soda process. The **washing room** or **wash-tank room** is that part of the mill where this separation is made.

The man in charge of this department has three objects in mind: 1, to prepare clean brown pulp fast enough to keep the bleachers supplied; 2, to keep ahead of the digesters, *i. e.*, to have tanks ready when the digesters are ready to blow; 3, to have the black liquor in the strongest condition possible, *i.e.*, in such shape that there will be the least quantity of water and the greatest quantity of solid matter in it.

The third object is necessary in order to reduce the work of the evaporators in their part of the reclaiming process and to reduce the amount of heat they consume in doing it. The brown pulp must be free from black liquor; otherwise, it will not bleach to a good color.

The pulp can be washed most quickly in shallow vessels, using only hot water, the hotter the better. But, in order to keep the black liquor strong, it is necessary to have the **washing tanks,** or **pits,** or **pans,** as they are variously called, of considerable depth, and to begin the washing process with some weaker black liquor, which has drained from tanks filled previously.

83. Washing Tanks.—The washing tanks may be round, square, or oblong in shape, and they are usually built with open tops. They are made of steel plate, well riveted up, and a convenient size is one that will hold one digester of pulp. By having the tanks of this size, it is easier to keep separate the pulp received from the different digesters.

A false bottom of heavy steel plate *A*, Fig. 13, perforated with holes of about ½ inch diameter, closely spaced, and having a thin, finely perforated plate or wire net *B* resting on it, is supported 6 inches from the bottom by steel beams *C*, fastened to the bottom, and by an angle iron *D*, riveted around the inside of the tank. The perforated plate is bolted to the angle iron and to the flanges of the beam, and the joints in the thin, perforated plate are held

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tight by means of iron straps. Below the false bottom, are the outlet *P*, for liquor to the liquor lines, and the outlet *E*, for waste water to the drain. There is also an opening *F* in the side of the tank, just above the false bottom, for washing out the brown pulp.

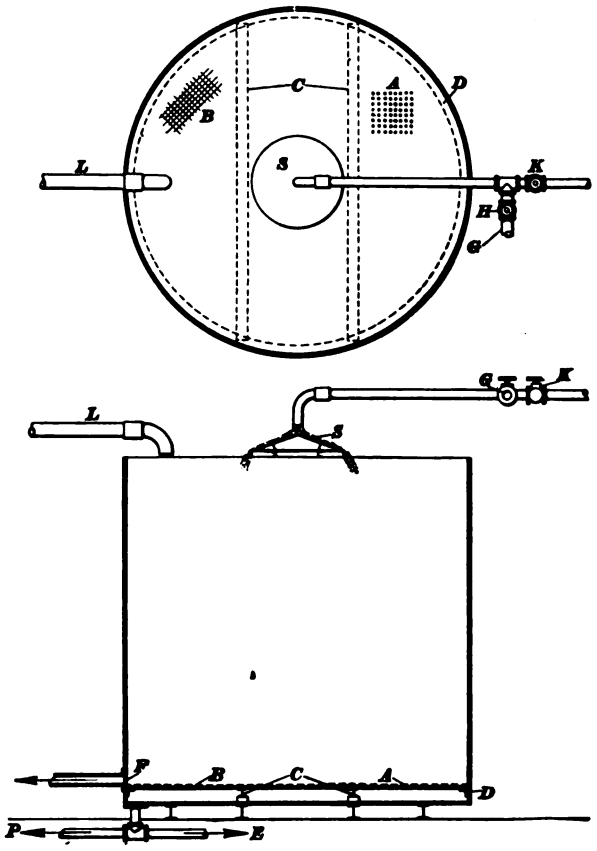

Fig. 13.

84. Piping in the Washing Room.—Wrought-iron piping is used in the washing room; this is neither rusted nor clogged up by black liquor. Each washing tank has a pipe *G*, Fig. 13, and valve *H*, for running on black liquor, and a pipe *K*, for running on warm water for washing. It is a good plan to have both these pipes connected to one pipe around the top of the tank, or across it, which should be perforated with small holes, for sprink-

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ling weak liquor or water over the top; or a distributor *S* may be used. A pipe having a high-pressure hose connection is provided to wash out the clean pulp from the tank. The black pulp from the blow pit is led into the washing tanks by means of a large, jointed pipe *L*, one end of which swings over a series of tanks and discharges into any one of them.

85. Pulp Canals or Sluices.—Washing tanks for soda pulp are supported on piers, and there should be room enough under them to permit a man to walk around easily and inspect the tanks for leaks. The pulp outlet from each tank connects to a **canal** or **sluice,** through which the brown pulp and water run to the next department.

The floor of the washing room basement should be well drained; and it is well to have an arrangement for measuring and testing the volume of liquid that runs away from the washing room, in order to keep watch of the loss of alkali. The measuring is done by means of a weir, which was described in the Section on *Mechanics and Hydraulics*, Vol. II.

86. Operation of the Washing Room.—The black pulp is taken down from the blow pit with the help of black liquor, which is pumped up for that purpose. In order that the first part of the blow may not pack too hard on the false bottom and thus make it difficult for the liquor to filter through it, the valve that controls the outflow of the strong liquor is not opened full until the tank is about one-third full. Care is also taken to keep the spout moving, so the pulp may not form a dense mass directly under the discharge pipe, which might wash more slowly than the rest of the pulp in the tank. When the tank is full, the weak-liquor valve is opened, to let weak liquor flow on the top of the mass of pulp as fast as the black liquor is discharged at the bottom. This weak liquor shows from one-third to one-half the strength of the average of the strong black liquor that is being pumped to the evaporators.

The time that the weak liquor is kept running on the pulp is gauged by the strength of the strong liquor flowing away from the tank. The accompanying diagram, Fig. 14, shows the rate at which the strength of the black liquor decreases at certain intervals of time.

The curve, Fig. 14, shows the gradual variation in the density of wash liquors from a typical soda cook of poplar wood, as the

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washing progresses. Testing began after 10 minutes draining, and it will be noticed that the readings were taken with a Baumé hydrometer at 100°F. The density increased slightly during the first half hour; then, for the next hour, it gradually fell off. At this time, washing with weak liquor stopped, and hot water was turned on for the rest of the washing period, during which time, the density fell off rapidly. The first stage, about to point *A*

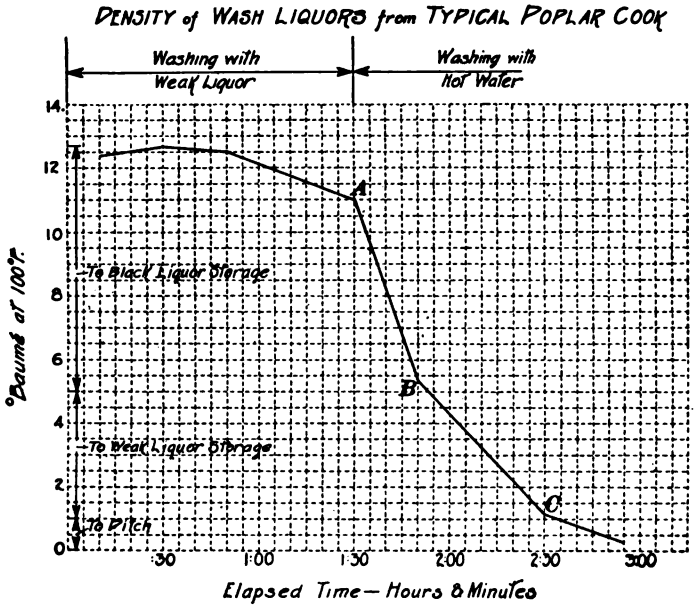

FIG. 14.

on the curve, shows the black liquor leaving the pulp as it is displaced by the weak liquor; this liquor goes to the evaporator storage tank. During the second stage, from *A* to *C*, the weak liquor wash is being displaced by hot water; a part of this, say to point *B*, may be mixed with the black liquor, while the rest goes to the weak-liquor storage, for washing pulp, etc. After point *C*, the effluent contains little of value and goes to the ditch. Points *A*, *B*, and *C* are not fixed, even for the same mill, but must be varied slightly, according to conditions. For instance, if the weak-liquor storage is full, the effluent must be discarded before point *C* is reached. Details of the cook represented by the curve are shown in the following tabulation:

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Kind of Wood	Gum and poplar
Wood per digester	3.7 cords
Volume of cooking liquor	3750 gal.
Strength of cooking liquor	12.5°Be.
Time of cooking	8 hours
Average cooking pressure	118 lb. per sq. in., gauge
Yield per cord	1150 pounds

The outline of the curve will vary with tanks of different shapes and dimensions and also with changes in the method of cooking.

87. When this strong liquor reaches the lowest strength (1.036 sp. gr.,) permitted to go into the strong-liquor storage, the strong-liquor valve is shut and the weak-liquor valve at the bottom of the tank is opened. At the same time, the weak liquor is shut off from the top of the tank, and warm water is turned on. The tank is kept flooded with hot water, which gradually sinks through the pulp, taking the place of the liquor and washing the pulp as it goes down through it.

When the strength of the weak liquor becomes so low (drops from 1.036 to 1.005, average, 1.02 sp. gr.) that the soda in it is not worth the cost of boiling down the liquor, the drain valve is opened and the rest of the weak liquor is wasted. The strength of the discharge to the drain is 1.005 sp. gr. (1°Tw.) or less. The hot water, 90°–120°F., that is used for washing the pulp, is taken from the condensers of the evaporators, or from the outside liquor heater (Art. **44**). The temperature of the weak liquor is usually 140°F. or higher.

When the pulp is entirely clean, the wash-out valve is opened and the pressure water (35–50 lb. per sq. in.) is turned on. The pulp and water flow through the pulp sluices into the next department, where it is to be screened and bleached.

88. It has been found that the manner in which the wood is cooked has a great effect upon the time required to wash it. Stock that washes easily and quickly is called **free stock,** while that which takes a longer time for this is called **slow stock.** Increasing the proportion of caustic soda to wood in the digester and prolonging the time the wood is cooking, tends to make stock slow, *i.e.*, it holds water and solutions longer. The reason is that cellulose hydrate, a gelatinous substance, begins to form on the fibers; the same phenomenon is observed in the case of greasy paper stock that has been beaten a long time.

At the instant the pulp drops from the discharge pipe, it is of a

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reddish-brown color, which turns to black almost instantly, the change of color being probably due to the action of air; but in the wash tank, the pulp is a great black, pudding-like, mass. Unless the pulp is under-cooked, there is now no appearance of the chip form.

If only fresh hot water were used in washing the pulp, it would be well and quickly washed, but the average strength of the black liquor would be low. This means that the evaporators must then boil more liquor and the fireman must burn more coal under the boilers, for each pound of soda recovered from the black liquor. Hence, washing with hot water only, will make the pulp cost more. Weak liquor is strengthened by passing it through the fresh pulp, thereby removing most of the black liquor adhering to the pulp. Cold water could be used instead of hot water, but the pulp would wash more slowly and would be harder to bleach. When cold water is put on black pulp, the washed pulp has a pink color; further, if cold water were used, there would be but little, if any, use for the hot water that comes from the evaporator condensers, and the heat in it would be wasted.

89. In the manufacture of sulphate pulp, the washing is done in closed vessels called diffusers (see Section on *Sulphate Pulp*), which are arranged in a series. The wash water enters the one first filled and passes through fresher charges until, finally, the now strong wash displaces the black liquor from the one last charged.

90. Analysis of Black Liquor.—The proportions of organic and inorganic constituents of the black liquor are indicated in the following analyses, which were made on an average sample of the liquor that first drained away from the stock. This liquor tested $12\frac{3}{4}$°Be. at 70°F., and 1 liter weighed 1097 grams.

Black liquor	Grams per liter	Per cent by weight	Per cent on total solids
Total solids	180.2	16.4	
Water	917.3	83.6	
Caustic soda	19.5	1.8	10.8
Total alkali as Na_2O	49.9	4.5	27.7
Organic matter precipitated by H_2SO_4	27.3	2.5	15.1

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THE EVAPORATOR ROOM

91. Purpose of Reclaiming Department.—The purpose of the reclaiming department is to save the alkali in the black liquor, in order that it may be used again, thus saving the use of fresh alkali. While the black liquor contains other substances of considerable value, practical methods of separating *all* of them have not yet been found, although experiments have been made with this in view. Some of the early soda mills wasted all the black liquor and had no reclaiming department whatever. As may be supposed, the first arrangements for reclaiming soda were not only crude but were also uneconomical.

The black liquor contains part of the caustic soda and all of the soda ash that was contained in the caustic liquor pumped to the digesters; it also contains dissolved woody substances and a portion of the soda, the latter being in chemical combination with acid substances derived from the wood; it likewise contains a substance of the nature of sugar and contains coloring matters. The following is an analysis from a soda cook of poplar, based on total weight of solids dried at 100°C. (212°F.), according to Griffin:

	Per Cent
Silica (SiO_2)	0.11
Oxides of iron and alumina (Fe_2O_3 and Al_2O_3)	0.02
Lime (CaO)	0.05
Potash (K_2O)	0.69
Soda (Na_2O)	25.69
Carbon dioxide (CO_2)	3.43
Acetic acid ($C_2H_4O_2$)	9.80
Organic matter extracted by naphtha	1.56
Organic matter extracted by ether	7.14
Organic matter extracted by alcohol (abs.)	28.26
Organic matter extracted by water	17.02
Total alkali by titration of incinerated residue	44.25

92. Black liquor that drains away from the pulp through the false bottom of the washing tank is likely to have some pulp in it; hence, before sending it to the evaporators, it is necessary to remove this pulp. Various forms of filters have been used for this purpose. Burlap bagging has been used as a filtering material in tanks having false bottoms. Pulp fibers have a tendency to plug feed passages, valves, and tubes of the evaporator and to lodge on the heating surface; it should therefore be removed before entering the evaporators. Revolving cylinders that are

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covered with metal cloth have also been used as filters, and one type was shown in Fig. 3.

The first step toward saving the alkali, after freeing the black liquor from particles of fiber, is to boil it down, or evaporate it, so there will be more solid matter and less water in a given amount of it. In the early forms of evaporators, the black liquor was boiled down by means of the direct flame from the black-ash furnace.

93. Multiple-Effect Evaporator.—Modern evaporators are all heated by steam; they are so constructed that a pound of steam admitted to them will have several times as great an effect in boiling (and, consequently, evaporating) the liquor as would be obtained by using the same steam in single kettles or cauldrons. Since the same steam is used in several different parts of the apparatus, in each of which the steam has an effect in inducing evaporation, the term **multiple effect** is given to this process of evaporation. All multiple-effect evaporators have certain distinct features and, also, many in common.

The layout of a **triple-effect evaporator** (one having three effects) is shown in Fig. 15. To feed the liquor to the evaporator, a pump or gravity feed may be used, and some form of regulator is often employed. The **evaporator bodies,** or **effects,** see *A*, Fig. 15, are the parts of the system where the actual boiling takes place. These bodies contain tubes that have steam on one side and the black liquor on the other side. The steam may be inside the tubes and the liquor outside, or the liquor may be inside and the steam outside; and the liquor may be in thin films on the surface of the metal, or it may be in large masses surrounding the tubes, according to the make.

Between the evaporator bodies, are *separators*, or *catch alls*, *S* for the purpose of separating any liquor that may be in the steam passing from one effect to the next. There must also be some means of creating a vacuum, such as a *condenser X*, with or without a vacuum pump. A tail pump *W* takes the liquor out of the evaporator.

Evaporators are constructed with the different bodies, or effects, either side by side as in Fig. 15, or arranged one above the other. In the latter case, the liquor is fed into the uppermost effect, and flows down into the lower ones.

The hydrometer test of the black liquor, as it comes to the evaporators, may be about 14°–15°Tw. (say 9½°–10°Be.), and

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the boiled down (evaporated) liquor may test over 70°Tw. (say 38°Be.), nearly four-fifths of the water in the liquor having

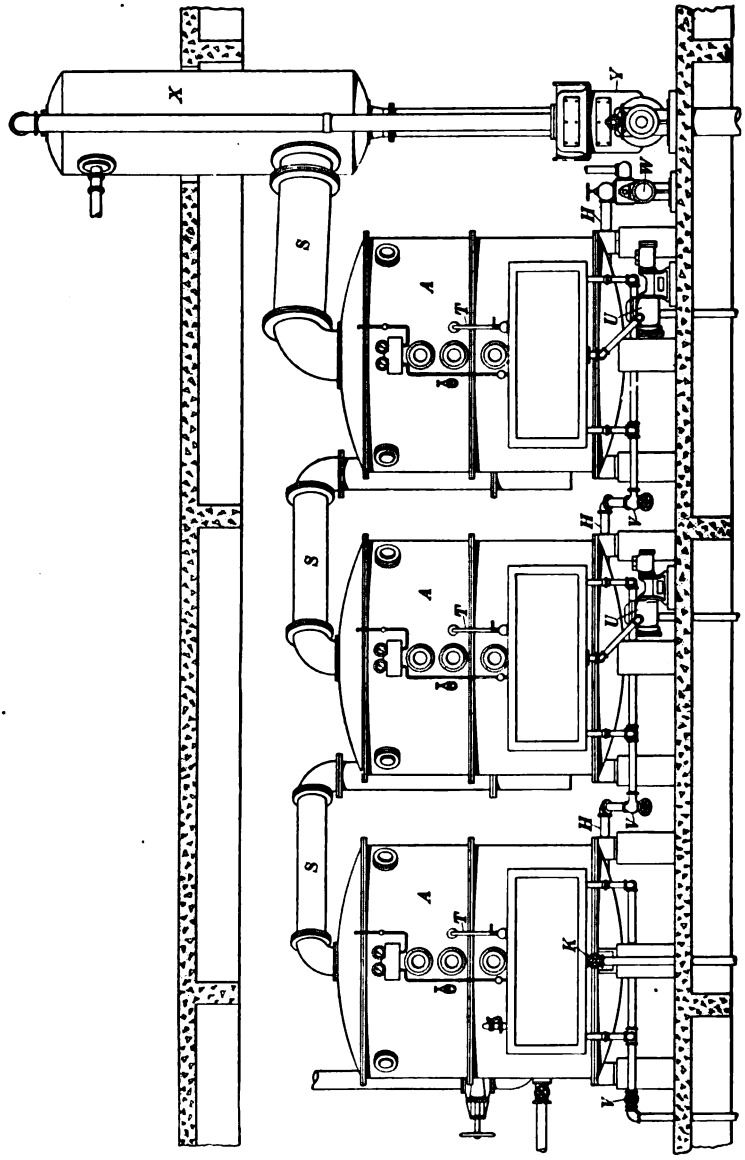

Fig. 15.

been removed by evaporation. A part of this water condenses on the heating surface of the evaporator, and is returned with the

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condensation from the first effect to the boilers; the remainder goes to the condenser, and is used to provide hot water for washing pulp.

94. Duties of the Evaporator Man.—The evaporator man regulates the feed and discharge, and also the steam pressure and vacuum in the several effects, with the object of making the outgoing liquor of such strength that it will act well in the black-ash furnaces. He must also wash the machines regularly, since they cannot do good work without washing, and he must keep the pumps well packed and in good order. A great deal of the success in recovering alkali depends upon the evaporator man.

95. Evaporator Details.—In Fig. 16, is shown a section of one of the effects (an **effect** is also called a **body** or **pan**) of the layout illustrated in Fig. 15. Here *A* is the shell, in the bottom half of which is a nest of tubes *B*. The tubes do not occupy the entire sectional area of the shell (not counting the space between the tubes), but leave a segment on either side for liquor circulation. The pipes are all of the same length, and they connect the steam chest *C* with the space *D*, in which the condensation separates and leaves by the valve *E*. Steam enters at *F*, either fresh steam or vapor from a previous effect. Similar letters in Figs. 15 and 16 indicate the same detail in each.

Black liquor enters at *G* at such a rate that the tubes *B* are covered. As the liquor heats, it rises through (or past) the tubes, gives up its vapor, and returns by the segment on either side of the tube nest. The liquid is heated by the latent heat in the steam that condenses in the tubes. The concentrated liquor collects in the bottom and passes through valve *H* to the next effect or to the rotary furnace room. *K* is a clean-out valve. Peep holes *L* enable the operator to watch the behavior of each unit, and the gauge *M* shows the pressure in the vapor space *N*; this pressure determines the temperature at which the liquid boils and, consequently, the pressure and temperature needed for the heating steam. *P* is an incandescent lamp. Since the vapor tends to carry away some drops of liquid, a separator, or baffle plate *R*, is placed below the vapor outlet *S*; the high vapor space greatly helps to diminish this trouble, which is called *entrainment*. As shown in Fig. 15, the vapor goes to the next effect, and from the last effect, to the condenser *X*. The liquid-level gauge glass *T*, feed control valves *V*, condensation pumps *U*, the tail,

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magma, or heavy-liquor discharge pump *W*, condenser *X*, and vacuum pump *Y*, for the removal of insoluble and non-condensible gases from the condenser, are also shown. It will be perceived that the vapor pipes *S* increase in size as the evaporation progresses; this is because the volume of any gas increases as the pressure decreases.

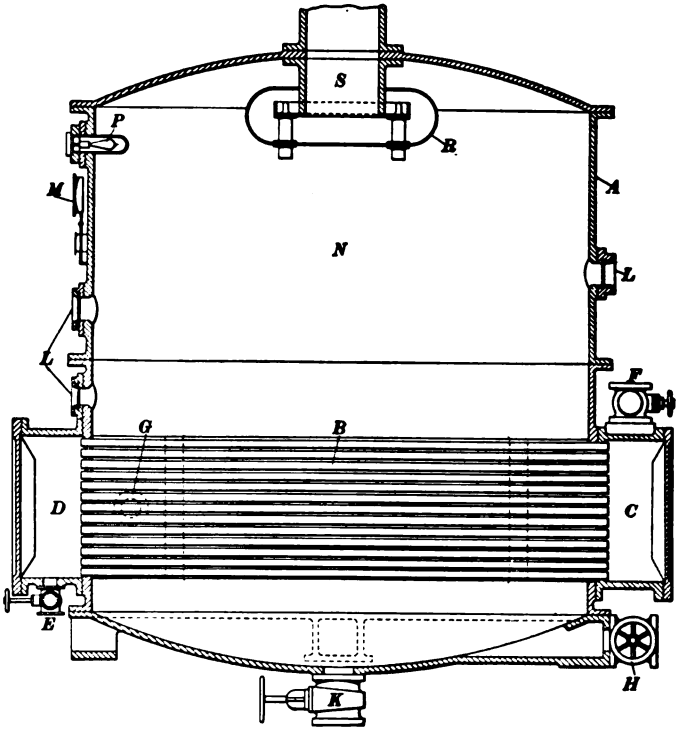

FIG. 16.

If exhaust steam is used in the first effect, its temperature will be about 225°F., and the general efficiency of the condenser and the cost of maintaining a good vacuum will ordinarily limit the temperature in the last effect to about 125°F. If a triple-effect evaporator is used, the vapor temperatures for effects 1, 2, and 3 will therefore be about 225°, 175°, and 125°, respectively. Since steam is used only in No. 1 and condenser water only in No. 3, the increase in efficiency over using three single-effect evaporators is obvious. This subject is discussed more fully in the Section on *Sulphate Pulp*.

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There are several makes of evaporators that have horizontal tubes, which are submerged in the liquid, and in which the steam condenses.

96. Film Evaporators.—The evaporator shown in Fig. 17 is commonly built in either three or four effects. Each effect has a feed head *B* and a discharge head *C* at the ends of a series of tubes. These heads are divided into a number of sections in such a manner that the tubes *D* form a series of manifolds or

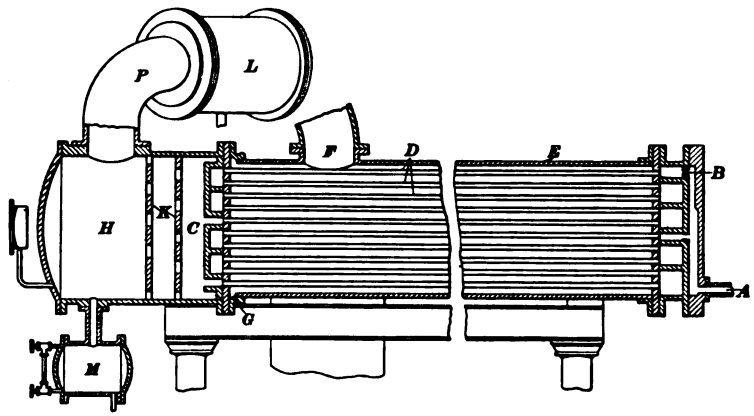

FIG. 17.

coils. The black liquor is fed into the first tube of a coil through a hole in the feed head *B*, and it escapes from the last tube of the coil through the discharge head *C*. The heating steam is confined in the shell *E*; it is introduced at *F*, and the condensate is withdrawn at *G*. Live steam is used in the first effect, the second effect is heated by vapors from the first, and so on. The condensation of the vapor here reduces the pressure on the liquid in the preceding effect, causing it to boil at a lower temperature, and therefore requiring less heat to evaporate it. The boiling of the liquor causes a great increase in volume, and this causes a rush of foamy liquor, which spreads a *film* of liquid on the sides of the tubes.

For low pressures of steam (vapor), the temperature varies greatly for slight changes in pressure. Thus, the boiling point of water (temperature of steam) at 20 lb. per sq. in. pressure, absolute, is 228°F.; at 14.7 lb. (ordinary atmospheric pressure), it is 212°F.; at 10 lb., it is 193.2°F.; 5 lb., it is 162.3°F.; at 2 lb.,

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it is 126.3°F.; at 1 lb., it is 101.8°F.; at 0.5 lb., it is 82.0°F.; and at 0.1 lb., it is 43.1°F.

An effect of common size has 22 coils of five tubes each. A soda mill equipped with this type of evaporator ought to have at least one evaporator coil per ton of daily production.

96. The liquor escaping from the evaporator coils separates from the vapor in a large separating chamber *H*, Fig. 17, which is provided with baffles *K*. From this separating chamber, the vapor passes through pipe *P* to the shell of the next effect, where it acts as a heating agent. Any liquor carried by the vapor is separated from it in the catch-all *L* and flows back to the chamber *H*. When the effects are placed one above the other, the liquor flows by gravity from one effect to the next. The density of the liquor gradually increases from 1.07 sp. gr. (14°Tw., say 9½°Be.) to 1.325–1.350 (65°–70°Tw., say 35½°–37½°Be.) for the finished, thick, black liquor, which is discharged through the trap *M*, and is fed to the coils of the next effect or to the rotary furnace room. Fresh liquor enters at *A*.

The vacuum pump creates a reduced pressure in the separation chamber and tubes of the final effect; the result is that the liquor boils at a much lower temperature, and the boiling can be effected by the vapor set free in the previous effect. Not being provided with a large dome, there is much chance for liquor to pull over.

In the Section on *Sulphate Pulp*, a description is given of a disk evaporator that is sometimes used in soda-pulp mills.

97. According to Sutermeister, recent examinations of black liquor from poplar wood gave the following data:

Degrees Be. at room temperature	Grams dry matter per 100 grams of liquor	Boiling points in degrees C. at the following pressures in inches of mercury[1]				
		41 in.	20 in.	0 in.	10 in. (vac.)	25 in. (vac.)
7	7.8	124.5°	114.3°	101°	90.5°	58.5°
16	18.5					
22	27.1	128.0°	117.5°	104°	93.0°	62.0°
27	36.6					
32	46.8					
37	57.6	135.5°	124.7°	112°	100.9°	69.0°

[1] 29.92 inches of mercury corresponds to standard atmospheric pressure, 14.7 lb. per inch, at 60°F.

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98. Evaporator Troubles.—In the type of evaporator described in Fig. 17, the gaskets between the heads and the tube sheets give the most trouble, because of the small contact surfaces. The breaking of a gasket allows the liquor to short circuit, as it were, and thus cuts down the number of tubes that are working. When the gasket breaks on the final (last) effect, a thick, gummy liquor is likely to be formed in some of the tubes, which clogs the screen of the separating chamber. This result is due the presence of too little liquor in some of the tubes and too much liquor in some of the others. When there is too little liquor present, it boils down too thick.

The tubes are sometimes coated on the liquor side with a scale of mineral matter; this is loosened by scraping, and is washed out when the machine is being overhauled; the tubes may become coated on the steam side also. The coating looks like carbon; it is caused by liquor getting into the steam or vapor.

The little feed holes through which the liquor enters the coils, may plug up with scale, pulp, or packing; the gasket may give out; a tube may wear through; a tube may start leaking where it is expanded into the tube sheet; any one of the pumps may slow down or stop working altogether; holes may wear through the heads, because of the cutting action of the liquor passing through them; and there may be trouble with the valves, gauges, and piping.

99. Vertical-Tube Evaporators.—In other makes of evaporators, where the liquor is in the tubes, the machines are set vertically, and the vapor separates from the boiling liquid in the space above it. In every such case, the liquor *flows* from the first effect to the last one, where the vacuum is maintained by a condenser, which is generally assisted by a pump.

Some evaporators require only a tail pump to remove the thick liquor. If a gravity feed is not provided, a feed pump is necessary. Care must be taken that the packing of the pumps is in good order; otherwise, the loss through leaks may be considerable.

An evaporator of the vertical-tube type is described in the Section on *Sulphate Pulp*.

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BURNING AND LEACHING BLACK ASH

BURNING BLACK ASH

100. Changing Black Liquor to Black Ash.—The thick, black liquor that is pumped away from the last effect of the evaporator looks very much like molasses; it contains all the soda and all the intercellular substances dissolved from the wood, except what was wasted in the washing and evaporating departments.

In order to use the soda over again, it is necessary to separate it from the non-fibrous part of the wood that it has helped to dissolve. To get back the soda, the mills now heat the liquor in a revolving, or rotary, furnace. The heat drives away the water that remains in the concentrated liquor, and then begins to char the woody material that remains. The latter finally begins to burn with a yellow flame until a considerable part of it is consumed; what is left is a red-hot cinder, known as **black ash,** which drops out of the discharge end of the furnace and is conveyed to the leaching tanks. This cinder is essentially a mixture of carbon and sodium carbonate, because practically all the organic compounds of sodium are converted to carbonate when heated in a current of air.

There is some loss of sodium compounds in the flue gases and in the causticizing-room sludge; this is made up by the addition of extra soda ash in the causticizing tanks.

The flow of liquor to the rotary is so regulated by the rotary runner (operator) that it is all converted to black ash; at full capacity this makes 15–20 tons of soda ash for each rotary furnace.

101. The Rotary Furnace.—The furnace in which the black ash is burned is a steel cylinder *b*, Fig. 18, adapted from Sutermeister. In many of the early furnaces, the length of the cylinder was 15–20 feet, but furnaces as long as 30 feet, have been used in modern practice; the diameter is from 9 to 10 feet, and the cylinder is lined with red brick. The furnace has heavy rings (tires) *c* riveted around it, which roll upon wheels *d* that have chilled cast-iron rims. A small engine *m* or other source of power is used to turn the furnace by means of gearing or a link belt. A large gear *e* is fastened to the shell in sections, and this meshes with a pinion that is connected to the source of power. In some cases, the chilled wheels transmit the motion to the furnace by friction. A cross section on line *AB* is shown in view (*a*).

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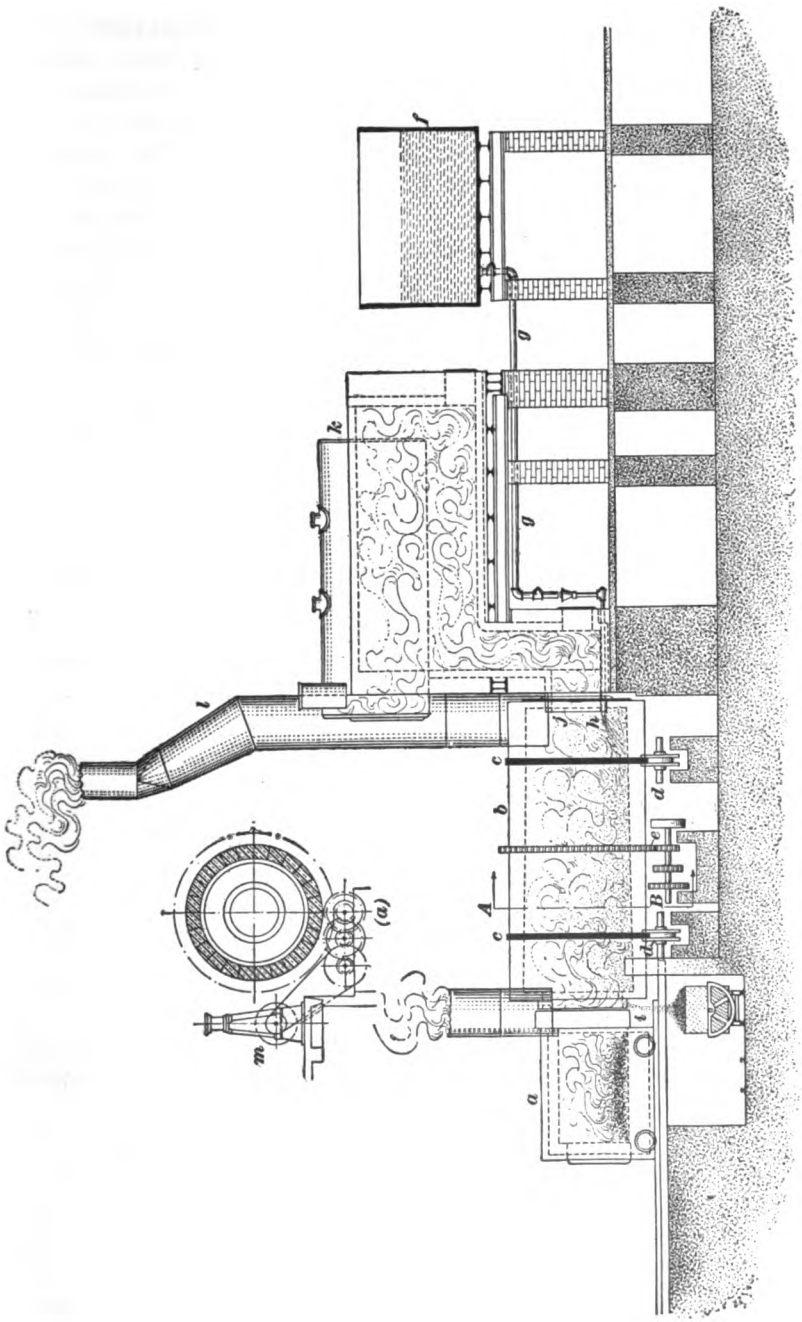

FIG. 18.

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At the end of the furnace, where the flame enters and where the red-hot cinder drops out, a ring of sections (of cast iron) *i*, called the **lip,** is bolted to the end of the shell in such a manner that the opening is somewhat smaller than the inside diameter of the furnace. This makes it possible to collect some of the burned and partly burned black ash in a considerable mass near the discharge end of the furnace, before it dumps into the car below or into whatever other means is provided for conveying the black ash to the dissolving tanks. The brick lining of the shell is thicker at the feed end than at the discharge end. This makes a slight slope, which causes the liquor and ash to move slowly toward the discharge end, as the furnace turns around.

In front of the discharge end, is a firebox *a*, sometimes called a **traverse furnace,** carried on wheels that run on a track. The firebox has a fire-brick roof, and it has a nozzle that projects a little beyond the lip into the rotary. The firebox is, ordinarily, close to the furnace; but it may frequently be moved away from it, when it is necessary to chisel out the hard masses of black ash that often stick to its sides. Fuel is burned on the grates of the firebox, and the flames pass through the nozzle into the furnace The liquor is gradually dried, as it passes forward, and the woody matter in it finally starts burning. The hot gases pass out of the same end *j* of the rotary that the liquor feed pipe *h* enters.

At this end of the rotary is an upright stationary flue *l*, which has a ring of castings attached to it at the lower end, forming what is called the **eye** of the rotary. The gases pass through the eye on their way to the waste-heat boiler *k*, which is always connected to the rotary furnace. If desired, however, the gases may be sent directly to the stack. The waste-heat boiler may be vertical or horizontal, and it may have either a fire-brick setting or a steel-plate setting lined with fire brick.

The hot gases from the rotary are useful in making steam, although they are not so hot as the gases from an ordinary boiler furnace. The temperature varies greatly; it may range from 900° to 1600°F.

The black liquor, which is running at the feed end of the rotary, grows gradually thicker as it moves forward toward the hotter end, where the flame from the firebox is coming in. A great deal of it adheres to the side of the furnace, which causes it to be carried upward as the furnace revolves, and it then rains

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down through the flames. The wet interior surface of the rotary exposes a large surface of the liquor to the action of the flames at this point.

At the place where the liquor becomes too thick to flow, a ring of dried or baked liquor forms around the rotary, which must be cut or chiseled off about three times each day, in order that there may be a free discharge of black ash from the furnace. The large masses that are thus chiseled off may have to be broken up into smaller pieces with a sledge hammer. The rotary need not be stopped for this purpose, however.

102. Once a week, when the rotary is shut down, the ash on the inside is picked off with a pickaxe, and the furnace is cleaned down to the brick lining. The tubes of the waste-heat boiler are also scraped, and any deposit of fine black ash is cleaned out.

The repairs necessary to make on rotary furnaces may be to the brick work of the firebox, the furnace lining, or to the waste-heat boiler setting, to the cast-iron work of the lip, the eye, and the firebox grates. The rails, the chilled-iron wheels, and the gearing also sometimes need renewal and repairs.

103. Furnace Troubles.—The following should be avoided and guarded against in operating the rotary furnace: weak liquor from the evaporators; cold furnace, due to poor firing; sliding of contents of furnace instead of the rolling movement that permits burning most rapidly. For the black liquor to burn easily, it should have a specific gravity of between 1.325 and 1.350; see Art. **96.**

LEACHING BLACK ASH

104. Object of Leaching.—The hot black ash is carried by a mechanical conveyor, or it may be washed out by a stream of water in a trough, into leaching tanks. Sometimes the dry ash is dumped into an empty tank and sometimes into a tank containing weak leached liquor. In either case, the next step is to separate the soda ash from the charcoal in the black ash.

As much as 80% of the weight of the black ash may be soda ash; the rest is charcoal and impurities. A part of the dissolved intercellular substances in the black liquor has been changed into charcoal and the rest burned. The separation is a very simple matter; water dissolves soda ash, but will not dissolve charcoal.

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The process of separating soda ash from the charcoal by means of water is called **leaching.**

105. Leaching Tanks.—The leaching tanks *A*, Fig. 19, are arranged with false bottoms *B* of perforated sheet steel. The black ash *C* rests on this bottom, and the water (with dissolved soda ash in it) passes through the perforations, leaving the charcoal behind. When the soda ash is all dissolved, the charcoal is discharged into the drain.

It is advisable to have several leaching tanks working in series, as shown diagrammatically in Fig. 19, which shows a

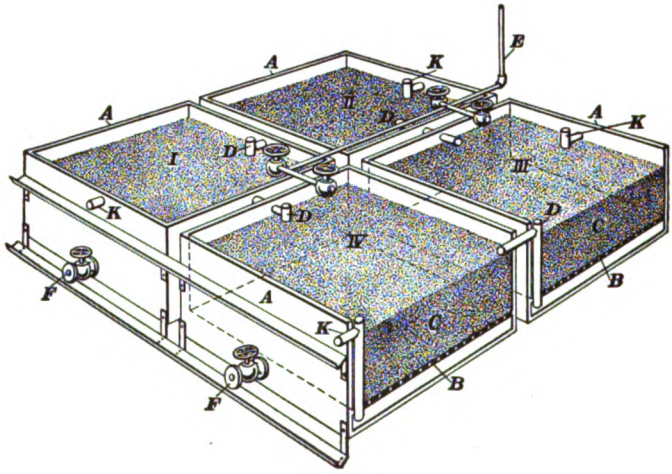

FIG. 19.

possible arrangement of four tanks, in which only the essentials are represented. The principle of operation is as follows: The charge that is nearly free from soda ash, say tank II, is washed with fresh water from pipe *E*. The weak liquor from tank II goes through overflow *D*, from below the false bottom, to tank III, which has more soda ash. The liquor from tank III is stronger, and may then pass to tank IV containing the fresh charge of black ash, where it reaches its greatest strength and is ready for causticizing. The strong green liquor is delivered at *K*. In the meantime, tank I is being dumped and filled with fresh black ash, when it, in turn, will be put in circuit as the *last* tank. When the liquor from this last tank weakens to a certain density, about 1.15 sp. gr. (30°Tw. or 19°Be.), it is turned into a

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tank of fresh black ash; the first tank is then dumped, and is ready for re-filling.

All these tanks are on the same level. The strong liquor flows by a pipe from the bottom of one tank to the top of the next, the liquor being forced upward by the weight of fresh water in the first tank. Wash-out valves are provided at *F*.

A centrifugal pump is generally used to convey the strong carbonate (green) liquor to the causticizing room. Warm water should occasionally be run through the piping, to prevent the formation of a mineral deposit.

106. Composition of Black-Ash Residue.—Some thought has been given to devising some way of using this charcoal as fuel. It is doubtless a good fuel if dry; but it holds so much water that the mills have not yet found a way to dry it cheaply enough to make its use as a fuel economical. Among other uses that might be mentioned is its employment as a decolorizing carbon.

The following is an analysis of the leached black-ash residue (carbon), which gives a good idea of its composition. The sample was first thoroughly dried and then exposed to the air.

Moisture, H_2O	6.06%
Sodium carbonate, Na_2CO_3	2.51
Calcium carbonate, $CaCO_3$	1.17
Sodium sulphide, Na_2S	0.37
Magnesia, MgO	0.34
Iron and alumina, Fe_2O_3 and Al_2O_3	0.26
Silica, SiO_2	0.17
Calcium sulphate, $CaSO_4$	0.07
Carbon (by difference), C	89.05
Total	100.00%

No use for this material that will even begin to take care of the amount manufactured has ever been developed. The most promising field seems to be its use as a fuel, since the heating value of the dried waste is 14,000 to 14,500 B.t.u. per pound.

THE CHEMICAL LABORATORY

107. How the Laboratory Helps the Mill.—The chemical laboratory helps in the successful running of the soda mills in several ways:

(a) By making an analysis of such crude materials as coal,

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lime, and salt. When this is done, and it is known that such analyses are made, the sellers of these materials are more likely to supply the grade agreed upon. To the mill using 50,000 tons of coal a year, a difference of 1% in the ash that the coal contains will make a difference of 500 tons of ashes, which the mill pays for as coal and has to handle as ashes after the coal is burned. The grade of a coal cannot be determined by simply looking at it. Actual trial is the best test, and a chemical examination helps the mill manager to decide whether or not he desires to make such trial; it also enables him to tell whether a large shipment is of the same grade as the trial lot.

(b) By keeping control of the chemicals that are in liquid form, and controlling the quality of the finished product. The hydrometer used by the men in the mill is not sufficient to keep this control, because there is no way of using this instrument that will enable one to tell what substances in the liquor make it of a certain hydrometric strength. For instance, a liquid that has 8⅔% of caustic soda, one that has 9% of soda ash, and one that has 13½% of salt will each show 20° on the Twaddell hydrometer and 13.2° on the Baumé hydrometer. There is no way, by the use of the hydrometer alone, that will enable one to determine whether a liquor is soda-ash liquor, caustic liquor, brine, or a mixture of these in any proportions. The chemist, however, has tests to ascertain this accurately, and he can specify the liquors for the digesters accordingly. Further, the amount of water in the pulp shipped to the customer must be known, if the weight of dry pulp, for which he pays, is to be invoiced to him correctly; and the color of the pulp must be kept so nearly to an established standard that it will be acceptable to the paper makers who use it.

(c) By devising improvements in the method of handling materials, from which much saving of chemicals may result. By more careful chemical control of the cooking, bleach may be saved, and economy in the use of wood may be achieved.

(d) When it is remembered that soda mills discharge as waste a large proportion of what enters as wood and all of the chalk calcium carbonate) that results from the causticizing process, it is easily seen that here is a broad field for the chemical laboratory. If these wastes are ever successfully converted into something of value, the laboratory will certainly have a large share in the work.

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SOME SIMPLE TESTS

108. A few simple tests, which may be useful to those working in a soda mill, will here be described. The ability to make these tests will not make a man a chemist any more than being able to apply first aid in case of accident makes a man a surgeon. Nevertheless, skill in making these tests will help a great deal in making things run smoothly about the mill.

109. Importance of Sampling.—It is first necessary to understand and remember that the sample to be tested must actually be like the large mass of material concerning which information is desired. Unless care be taken in selecting and preparing the sample, the result of the test will be worse than useless; because, in addition to getting incorrect proportions, a wrong idea will be formed regarding the material being tested. It is fully as important to do the sampling right as to perform the testing right.

Thus, if one were testing a tank of caustic liquor that had not been well stirred, and which had a weaker liquor on the top than on the bottom (the heavier liquor, of course, falls to the bottom), and a sample were taken from the top only, all the work of testing and calculating the results would give a wrong amount for the liquor to be pumped to the digester.

110. Control of the Causticizing.—The test about to be described is one for determining what proportion of soda ash has been changed to caustic soda in the process of boiling with lime.

When the liquor in the tank has been boiled and well stirred, it is certain that it is thoroughly mixed and that a sample taken from the tank with a long-handled dipper will fairly represent *all* the liquor in the tank. This sample is poured into a dipper having a short handle, and is allowed to rest for a few minutes, to allow the lime mud to settle. A few, say 10, cubic centimeters of clear liquor is then sucked up by means of a bulb in a certain form of glass tube called a *pipette*, which measures accurately.

The liquor is allowed to run out of the pipette into a flask that has a capacity of 250 c.c. (about half a pint). A few drops of phenolphthalein are then dropped into the flask, and the color of the liquor instantly turns to a dark pink. The phenolphthalein is called an *indicator*, and any liquid containing an alkali turns pink when this indicator is dropped into it.

By means of a measuring tube called a *burette*, a weak (*normal*) solution of sulphuric acid is added, drop by drop, to the pink liquid in the flask, and the flask is given a rotary motion, to keep

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the liquid well stirred. In a short while, the pink color becomes fainter and fainter, until shortly a single drop of the acid destroys the pink color entirely, leaving the liquid colorless. As soon as this effect is secured, stop adding acid.

The acid has thus far neutralized all the caustic soda (sodium hydrate) and half the carbonate in the liquor, as shown by the following equations:

$$2NaOH + H_2SO_4 = Na_2SO_4 + H_2O \quad (1)$$

$$2Na_2CO_3 + H_2SO_4 = 2NaHCO_3 + Na_2SO_4 \quad (2)$$

The number of cubic centimeters of acid that has been used is read off on the burette, and a few drops of a solution of methyl orange is added to the solution in the flask. Methyl orange is another indicator, and it changes the solution from colorless to a light yellow. More of normal sulphuric acid solution is then run from the burette into the flask, being added drop by drop, with careful shaking. As soon as a single drop of the acid turns the yellow color to a light pink, cease adding acid. The total quantity of acid that has been used is read off from the scale of the burette, and a calculation is then made. The second addition of the acid has completed the neutralization of the sodium carbonate, as indicated by the equation,

$$2NaHCO_3 + H_2SO_4 = Na_2SO_4 + 2H_2O + 2CO_2 \quad (3)$$

Hence, twice the difference between the first and second readings is the acid neutralized by (equivalent to) the carbonate not causticized, while the total acid consumed represents all the carbonate originally present. The total number of sodium atoms is the same, whether present as carbonate or as hydrate.

The first reading of the burette is subtracted from the second, the difference (which may be called the first difference) is multiplied by 2, and the product is subtracted from the second reading; the latter remainder (which may be called the second difference) is divided by the second reading of the burette (which is the total amount of normal acid solution used), and the quotient multiplied by 100 is the per cent of the total soda ash that has been causticized, *i.e.* changed to caustic soda.

Thus, assume the readings to be as here given, the original acid reading in the burette being 0 (zero).

Second burette reading (when yellow turns pink).....27.2 c.c.
First burette reading (when pink becomes colorless)....25.9 c.c.

First difference..... 1.3 c.c.

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Then, as directed in the last paragraph, $1.3 \times 2 = 2.6$ c.c. (= carbonate); $27.2 - 2.6 = 24.6$ c.c. (= hydrate) = second difference; $24.6 \div 27.2 = .904$, and $.904 \times 100 = 90.4\%$ = per cent. of carbonate converted or causticized.

To make the foregoing clear, let h = c.c. of hydrate and c = c.c. of carbonate. Suppose a c.c. of acid are required to neutralize all the hydrate and one-half the carbonate in the *first* reaction, and b c.c. of acid is used to neutralize all the hydrate and all the carbonate in the *two* reactions. Then,

$$h + \frac{c}{2} = a \qquad (1)$$

$$h + c = b \qquad (2)$$

Multiplying (1) by (2),

$$2h + c = 2a \qquad (3)$$

Subtracting (2) from (3),

$$h = 2a - b \qquad (4)$$

and $$\frac{2a - b}{b} \times 100 = \text{per cent. of hydrate.} \qquad (5)$$

Subtracting (1) from (2)

$$\frac{c}{2} = b - a, \text{ or } c = 2(b - a) \qquad (6)$$

and $$\frac{2(b - a)}{b} \times 100 = \text{per cent. of carbonate} \qquad (7)$$

In the particular case given, $a = 25.9$ c.c., $b = 27.2$ c.c.; hence, substituting in (5),

$$\frac{2 \times 25.9 - 27.2}{27.2} \times 100 = 90.4\% \text{ of hydrate;}$$

and substituting in (7),

$$\frac{2(27.2 - 25.9)}{27.2} = 9.6\% \text{ of carbonate.}$$

111. Testing Pulp for Moisture.—It is probable that no two mills use identically the same method for securing the samples to represent the pulp being tested. If the pulp be in rolls or bales the number of samples taken from each roll or bale may vary from one to ten. The size and shape of the sample may differ and the depth below the surface that the sample is taken may vary in different mills. Makers and users of pulp have cooperated in endeavoring to develope standard methods of sampling and analysis; the latest directions and methods are given in the Sections on *Bleaching of Pulp* and *Refining and Testing of Pulp*.

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QUESTIONS

(1) (*a*) Why must pulp be washed? (*b*) What are the principal constituents of black liquor?

(2) What two advantages are gained by first washing the fresh pulp with weak liquor from the previous washing?

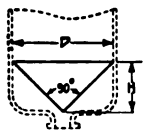
(3) Why is black liquor evaporated?

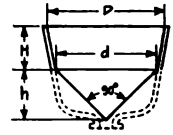
(4) For what purpose is the condenser attached to the multiple-effect evaporator?

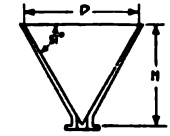
(5) Explain why a large amount of sodium carbonate is found in the black ash.

(6) What becomes of the solution obtained by leaching the black ash?

VOLUME OF BOTTOM CONE OF SODA AND SULPHITE DIGESTERS







Formula: $V = \frac{\pi}{20736} D^2 H$			Formula: $V = \frac{\pi}{20736}\left[HD(D+d) + d^2(H+h)\right]$						Formula: $V = \frac{\pi}{20736} D^2 H$		
D (in.)	H (in.)	V (cu. ft.)	D (in.)	H (in.)	d (in.)	h (in.)	V (cu. ft.)	v (cu. ft.)	D (in.)	H (in.)	V (cu. ft.)
72	36	28.27	72	51	44	22	85.95	6.45	72	44½	34.95
78	39	35.95	78	49	51	25½	104.06	10.05	78	48	44.24
84	42	44.90	84	48	54	27	117.43	11.93	84	51⅞	55.45
90	45	55.22	90	45	61	30½	135.22	17.19	90	55½	68.11
96	48	67.02	96	44	64	32	149.56	19.86	96	59¼	82.72
102	51	80.39	102	46	72	36	188.09	28.27	102	63	99.30
108	54	95.43	108	45	74	37	202.02	30.70	108	63⅞	117.73
114	57	112.23	114	42	82	41	226.73	41.77	114	70⅝	138.56
120	60	130.90	120	40	86	43	242.81	48.18	120	74	161.44

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MANUFACTURE OF SODA PULP

EXAMINATION QUESTIONS

(1) (*a*) State the principal difference between the mechanical process and the chemical processes of making pulp. (*b*) Which is the better for making high-class paper, and why?

(2) (*a*) How is the cooking liquor prepared for the soda process? (*b*) is it acid or alkaline?

(3) (*a*) Why does the recovery process fail to get all the soda used in the digester? (*b*) about what per cent is lost?

(4) What are the characteristics of a good lime for a soda mill?

(5) How would you remove the sludge from caustic liquor?

(6) What do you consider the best type of digester, and why?

(7) What are the advantages and disadvantages in external systems of circulating digester liquor as compared with internal systems?

(8) (*a*) How much steam is ordinarily required to cook a ton of soda pulp? (*b*) what becomes of the steam?

(9) Name the principal factors that affect the operation of the digester.

(10) Mention some of the sources of trouble in running a digester.

(11) As the washing of a tank of pulp progresses, at what density (specific gravity) is the black liquor turned from strong-liquor storage to weak-liquor storage, and when is it sent to the sewer?

(12) (*a*) Why should hot water be used for washing pulp? (*b*) Why is it not feasible to use all fresh water?

(13) Explain the advantages of a triple-effect evaporator as compared with three single effects.

(14) How is black ash obtained, and what does it contain?

(15) (*a*) Explain the leaching of black ash. (*b*) What substances are found in the solution obtained?

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SECTION 6

MANUFACTURE OF SULPHATE PULP

By KARL M. THORSEN, Chem. Eng.

ORIGIN AND OUTLINE OF PROCESS

1. Object of Process.—The **sulphate process** for making wood pulp is a modification of the soda process; it was introduced in Danzig in 1884 by C. F. Dahl, with the intention of reducing the manufacturing cost by substituting sodium sulphate (salt cake) for the more expensive soda ash. The new industry was well received in Sweden, Norway, and Finland, where vast quantities of saw-mill refuse and the smaller sizes of wood, which had previously been used as cheap fuel or wasted, were utilized. The product is known as **sulphate, or kraft, pulp.** The word *kraft* is from the Swedish and means strength, a characteristic of this fiber.

In America, the sulphate pulp industry is comparatively young. The first mill on the North American continent to manufacture this product was the mill of the Brompton Pulp & Paper Co. at East Angus, Quebec, which began making kraft pulp in 1907. In 1908, one mill was operated, with an estimated daily capacity of 25 tons; in 1918, there were 33 mills, with an estimated daily capacity of 1350 tons; in 1920, the estimated daily production in the United States and Canada was 2500 tons, which shows the constantly increasing popularity of the process.

2. Kind of Wood Used.—The woods employed for the manufacture of sulphate pulp are almost exclusively coniferous, though nearly all species have been used with more or less success. The pulpwood used in 1918 for the purpose of manufacturing sulphate pulp is reported by the United States Department of Agriculture as follows:

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TABLE I

Spruce	37483 cords
Hemlock	37829
Balsam fir	34444
Jack pine	10547
Yellow pine	90990
Tamarack	44865
White pine	8637
Slabs, and other mill waste	31754
Total	296549 cords

Wood used in soda-pulp mills that employ some salt cake to replace a part of the alkali required is not included in the above table.

3. Size of Chips.—The size of the chips should be as nearly uniform as is possible, in order to obtain a uniform result in the digester. A small chip will naturally cook faster than a larger one. Consequently, when the small chip is cooked, it must either be exposed to the continued action of the cooking liquor (which will affect the fiber) or the charge (cook) must be blown before the big chips are thoroughly cooked. In either case, there is a loss of material, both wood and chemicals, and a decrease in the number of pounds of fiber obtained per cook. The careful sorting of chips is thus of great importance, although the actual size of the chips may be varied within certain limits, if only they are uniform in size. A $\frac{5}{8}$-inch to $\frac{3}{4}$-inch chip gives the best results, but a chip about 1 inch long seems to enable the liquor to act uniformly all through it.

The figures in Table I show that only coniferous woods were used in the sulphate process. The rather severe treatment with alkali that is required in pulping resinous wood and the difficulty encountered in bleaching the fiber, have made coniferous woods less desirable for making soda pulp than the broad-leaved woods. However, by adopting the sulphate process, the action of the alkali is less destructive, and the excellent qualities of the fiber of the coniferous woods are preserved. The yield of the wood, figured on the basis of bone-dry fiber from bone-dry wood, is considerably higher when the sulphate process is used (45%–48%) than when the wood is cooked with pure soda liquor (38%–40%). The figures just given for sulphate pulp have reference to kraft pulp. For easy bleaching pulp, consuming from 11%–13% bleach, a yield of 40%–42% can be maintained.

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4. Character and Uses of Sulphate Fiber.—The fiber obtained by the sulphate process is remarkable for its strength and flexibility. The residues of resin that are sometimes found in the sulphite fiber are more completely destroyed by the alkaline treatment to which they are subjected in the sulphate process. Though the soda fiber is even purer than the sulphate fiber, the drastic action of the chemicals in the soda process robs the fiber of some of its strength. It is because of these properties that sulphate fiber has found use for making a paper that has great strength and durability; it is used, even, as a substitute for cotton, for making such washable fabrics as towels, aprons, mats, sacks, overalls, etc. Imitation leather for bags and also for shoes is made from sulphate fiber. An easy bleaching sulphate fiber, though consuming a higher percentage of bleach, is often preferred to the soda fiber.

The disadvantages of the process are the bad odors and the high cost of upkeep of the recovery room. The problem of making the smell less objectionable has yet to be solved. A shower, to wash the gases in the chimney, helps some; mixing the gases from the furnace with the combustion gases from the steam boilers before they go to the economizer, seems to be the most effective way, but it is expensive, since it lowers the temperature of the flue gases and increases their volume.

NOTE.—The steam relieved from the digesters and from the diffusers when a digester charge is blown out, is best taken care of by a condenser or by leading the escaping steam underwater.

5. Outline of Process.—Sulphate pulp is obtained by treating chips of wood with a liquor, the active components of which are *sodium hydrate* NaOH, (commercially called caustic soda), and *sodium sulphide*, Na_2S. The pulping of the chips is performed in a closed steel tank, or *digester*, under steam pressure. When the wood is properly *cooked*, the charge is *blown* (emptied) into wash tanks—*diffusers*—where the fiber is washed clean from the liquor solution—the *black liquor*—which results from the cooking. This black liquor is concentrated in *evaporators* of various design, and is finally evaporated in a *rotary furnace*, from which it comes out as a black, semi-solid material, called the *black ash*.

The black ash is burned in a furnace, where a brisk combustion is maintained, and the organic compounds of sodium are largely converted to sodium carbonate. The sodium salts used to

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replace the losses of chemicals during the process are added here. The *smelt* (molten salts) escaping from the furnace is run down into a tank—*dissolving tank*—filled with weak wash from the liquor room to dissolve. When the resulting liquor—the *green liquor*—has reached a certain strength, it is brought into another tank, called the *causticizer*, or *causticizing tank*, where lime is added and the liquor is left to settle. The resulting clear liquor—the *white liquor*—is then drawn off, and is ready for the charging of another digester.

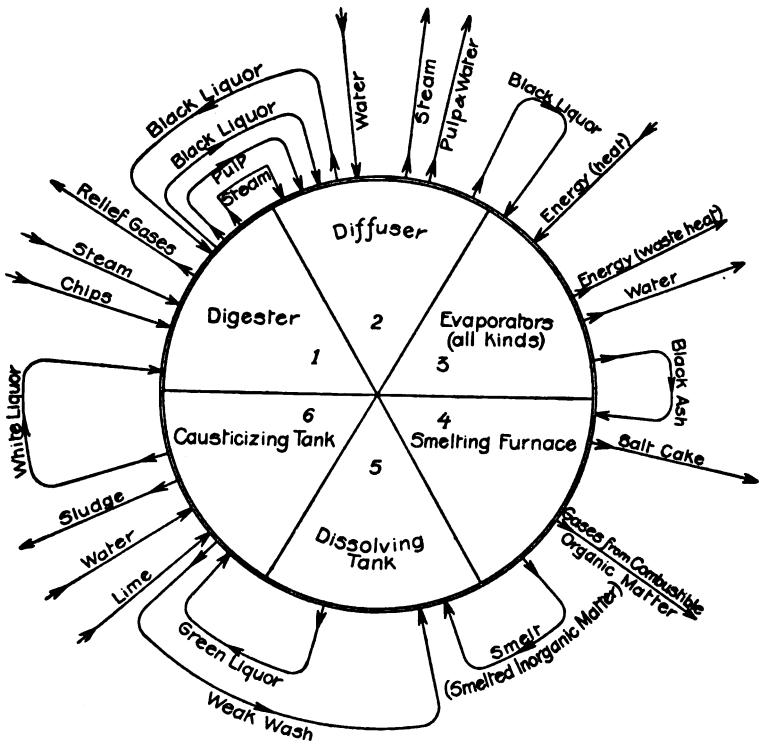

FIG. 1.

The various steps of the process are clearly shown by the diagram, Fig. 1, which will be more clearly understood after the following pages have been studied.

The diagram may be interpreted as follows: Beginning with space No. 1, the digester, the arrows show by the direction in which they point whether the substance whose name is printed on an arrow is entering or leaving the apparatus indicated by

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numbers from 1 to 6. The order of the operations is the same as the order of the numbers, which is clockwise around the diagram. Starting with No. 1, the digester is charged with white liquor from causticizing tank No. 6; it is also charged with chips and steam. The discharge from the digester consists of relief gases, destination not given (eventually, the atmosphere), and black liquor, pulp, and steam to the diffuser, No. 2. Note that the diffuser is charged with black liquor from the digester, and that some black liquor enters the digester from the diffuser. Considering No. 2, the diffuser is charged, as just mentioned from the digester and also with water. It discharges steam and pulp and water, as hereinafter mentioned, and black liquor to the evaporators, No. 3. By proceeding in this manner, each step of the process will be made clear. The diagram shows every step and its order in the process.

The different steps and operations will now be described in detail, beginning with the liquor room.

THE LIQUOR ROOM

CAUSTICIZING

6. Reason for Causticizing.—Because of its composition, the **green liquor** from the dissolving tanks (see Fig. 1) is not ready for use for cooking pulp. The green liquor, a typical analysis of which is given in Table II, contains a considerable quantity of sodium carbonate Na_2CO_3, which has practically no value as a resolvent of wood, *i.e.*, as a cooking agent. In order to convert this inactive sodium carbonate into active sodium hydrate NaOH, quicklime CaO is added to the green liquor in the liquor room, the sodium hydrate remains in solution, and a precipitate, or **sludge,** of calcium carbonate is formed. The sodium carbonate is said to be **causticized,** *i.e.*, made into caustic soda; thus,

$$Na_2CO_3 + Ca(OH)_2 = 2NaOH + CaCO_3.$$

The carbonate of lime, $CaCO_3$, which is not soluble in water, is separated from the liquor by settling, sometimes by filtering, and the liquor thus obtained is the **white (strong) liquor** that is used in the digester for cooking the chips.

7. Causticizing Tanks.—The operations just described are generally carried out in wrought-iron tanks, called **causticizing**

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tanks, which may be of different shapes, but are always equipped with an *agitator*, and it is very important that this agitator produces a thorough mixing. The utilization of the lime and the recovery of the alkali remaining in the sludge, are dependent on a thorough agitation. An agitator scraping well down at the bottom and on the sides and making about 14 r.p.m. will give satisfactory results.

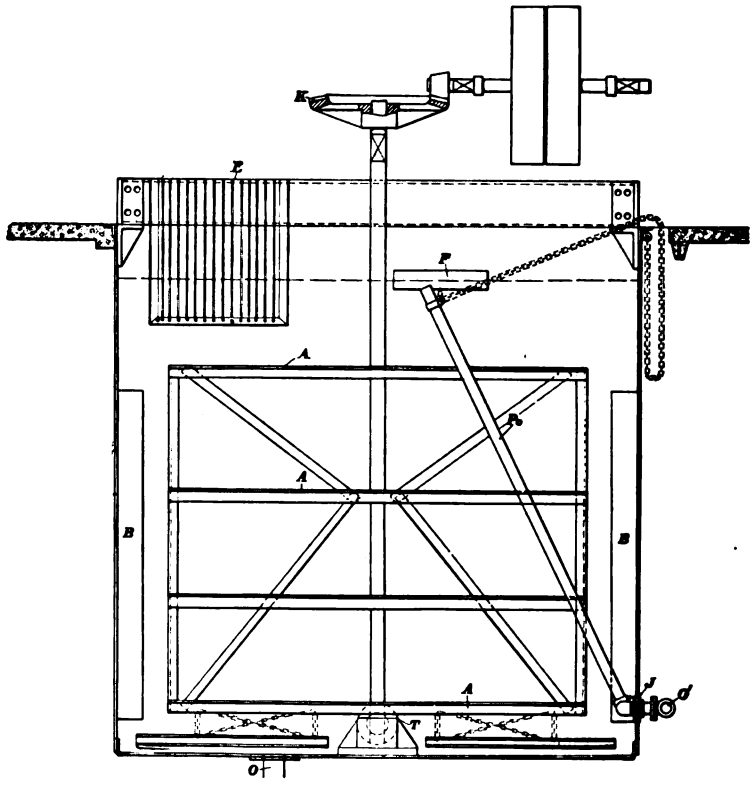

FIG. 2.

In the case of a tank shaped like a vertical cylinder Fig. 2, the usual form of causticizing tank, there is danger of finally reaching a state in which the entire contents of the tank turn around like a solid body, the particles following the agitator without mixing with one another. This condition may be remedied by attaching to the sides of the tank three or four angle-iron stationary arms *B*, which will retard the rotary movement

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of some parts of the liquor and produce a better mixing of the materials.

Good agitation is obtained in a horizontal rectangular tank having a semi-cylindrical bottom. The upper half of the tank may have vertical sides in this case, or the entire tank may be cylindrical. The agitator is mounted on a horizontal shaft, and consists of scrapers, which lift the lime sludge above the surface of the liquor and then let it fall back through the liquor or wash water, thus giving the contents a thorough mixing. The packing glands, where the shaft penetrates the end of the tank constitute the weak point of this type of tank; they are liable to leak and must be watched carefully. This construction has been modified, and the tank improved, by making the agitator shaft shorter than the tank and driving it by a sprocket wheel on the shaft, which is chain-driven from a shaft situated above the tank. The tank is provided with swivel outlet, pipes for heating with steam, lime baskets, and a wash-out opening.

8. Settling and Washing the Sludge.—The lime is generally separated from the liquor by letting the lime sludge settle, and then drawing off the white liquor by means of a swivel pipe P_o, Fig. 2. The separation is a case of one material falling through another. Here it is always a matter of lime in liquor, and the principal factor affecting the time required for a unit volume to settle is the distance the lime sludge has to fall, *i.e.*, the height of the tank. The same volume of sludge will settle more quickly in a shallow tank of large diameter than in a deep and narrow tank of the same capacity.

Whatever the type of tank used, it must be supplied with devices for admitting raw liquor, water, and steam. For the admission of steam, a perforated pipe, with the end closed, is to be preferred to an open pipe, and this pipe should go within a foot or less of the bottom of the tank. In the bottom of the tank is an outlet *O*, Fig. 2, for washing out the sludge. This outlet should be shut off with a disk or plug, seated in the outlet opening and flush with the bottom of the tank; in addition to this disk, it is advisable to have a plug cock or a gate valve on the outlet pipe, to make certain there is no leakage. If a plug cock only be used, there is a risk of getting the fitting between the tank and the cock plugged with sludge. The clear (white) liquor, which forms the upper part of the contents of the tank, is discharged through an outlet *O'*, placed about one to two feet above

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the bottom of the tank, where the swivel pipe P_o which reaches well up to the top of the tank, connects to a swing joint J. By letting the pipe P_o down as far as the lime has settled, the clear liquor is separated from the sludge. A float F, Fig. 2, is sometimes attached to the free end of the pipe; the float automatically keeps the open end of the pipe just below the upper surface of the liquor as it falls; but care must be taken that, as the pipe nears the bottom, it does not draw out sludge. The gear K drives the agitator, O is the outlet for the sludge; a fan pump delivers the white liquor to the storage tanks, in case these are not situated below the level of the causticizing tanks.

Causticizing tanks are preferably equipped with lime baskets B, Fig. 2, which are made from iron bars, spaced about 1 inch apart. The stones and unburned cores in the lime are held in these baskets after the lime has dissolved, and are easily removed. The sludge left in the tank is washed as described in Art. **17.**

9. Storage Tanks.—In addition to the causticizing tanks, the liquor room is equipped with **storage tanks** for strong and weak liquor. The storage tanks may be of any suitable shape, but should be fairly large, and should preferably be so placed that the liquor can run into them by gravity from the causticizing tanks above. The storage tanks should also be supplied with decanting pipes, similar to pipe P_o in Fig. 2 to separate the white liquor from any sludge that may have entered from the causticizing tanks.

10. Adding the Lime.—The lime may be furnished to the tanks from a bucket traveling on a trolley-way above the tanks, or a tilting bucket on tracks, but it is often handled in barrows; in either case, the lime should be weighed. In some mills, it is customary to causticize all liquor in one tank, from which the liquor, sludge and all, is pumped into the settling tanks. The lime is then added in one tank only, which makes for better working conditions and a cleaner liquor room, when the tank is built in and the room is properly ventilated. It is to be noted that, with this arrangement, the time that is used for the transportation of the liquor from the causticizing tanks to the settling tanks is lost time, insofar as the continuity of the process is concerned; and if power is required to pump from one set of tanks to the other, this power is wasted, since gravity might have been utilized.

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11. The lime that is best suited to use in the liquor room for causticizing must, of course, contain a high percentage of CaO, and lime having less than 85%–90% of CaO should not be considered; it must also contain but little magnesia, which impurity has a bad influence on the settling of the sludge; and the settling properties of the lime are of as much importance as the content of calcium oxide, CaO.

The best method of determining the value of lime for the liquor room is to make actual causticizing experiments on a small scale, when a certain quantity of green liquor is analyzed for sodium carbonate Na_2CO_3 and is treated with the quantity of lime that is theoretically necessary to obtain the desired result. An analysis of the white liquor thus obtained will show how much of the oxide is consumed in causticizing the liquor and the completeness of conversion; and observations of the time of settling and the volume of settlings, will give valuable information concerning the adaptability of the lime for the liquor room. When deciding which of several grades of lime to purchase, the analysis of the lime should always be accompanied by actual causticizing tests and settling experiments. Lime that settles quickly, with a small volume of settlings, and at the same time is high in percentage of available CaO is what is wanted; 60–65 pounds of such lime will causticize 100 pounds of Na_2CO_3.

The quantity of lime used per ton of pulp varies between wide limits; it is usually about 500 pounds, depending upon the causticity, per cent of sulphide in liquor, and the quantity of alkali used for cooking.

When lime is stored at the mill, the place of storage should be as dry and as air-tight as is possible.

CAUSTICIZING OPERATIONS

12. Composition and Analysis of Green Liquor.—The composition of the green liquor varies greatly, even the composition of the green liquor of successive batches varies. Its main components are sodium carbonate (Na_2CO_3) sodium sulphide (Na_2S) sodium hydrate (NaOH) and sodium sulphate (Na_2SO_4); but there are also sodium sulphite, Na_2SO_3, sodium thiosulphate, $Na_2S_2O_3$, polysulphide of sodium, sodium silicate, sodium aluminate, and salt, NaCl. It is not essential that the liquor be

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analyzed for all these components; in fact, for every-day analysis, it is sufficient to find the carbonate, sulphide, and hydrate of soda; and for the control of the smelter work, to determine the sulphate and sulphite, as will be shown later. Table II gives typical analyses of two different green liquors, the density of both being 20°Be. and the temperature 190°F. The losses of salt cake were 500 pounds per ton of pulp; the first strong wash was used with the strong liquor, and the succeeding washes were used in the dissolving tanks.

TABLE II

	Grams per liter	Pounds per cu. ft.	Grams per liter	Pounds per cu. ft.
Na_2CO_3	138.35	8.637	153.17	9.562
NaOH	16.80	1.049	12.40	0.774
Na_2S	71.76	4.480	71.76	4.480
Na_2SO_4	16.11	1.006	14.41	0.900

NOTE.—Grams per liter may be expressed as pounds per cubic foot by multiplying the numbers of grams per liter by .062428.

13. The component of greatest interest in the liquor room is the amount of sodium carbonate in the green liquor, since this determines the quantity of lime that is needed for the batch. By taking analyses from several charges of the green liquor and of the white liquor that results, it will soon be found what is the smallest quantity of lime that is needed to obtain the degree of causticity desired. In every-day practice, it will give just as much satisfaction, with less trouble, to fix this minimum quantity of lime to be used, and then let the liquor maker analyze the liquor, to ascertain whether its composition is what is wanted and if not, how much more lime must be added; the latter he can find out from a table that has been computed for this purpose. This method has some advantages in practice over having an analysis made of each tank of green liquor and finding from this analysis the total quantity of lime required. In the latter case, a control analysis of the ready white liquor may call for an additional quantity of lime, because of variations in the composition of the lime, and this additional quantity will often be a very substantial amount. On the other hand, if the minimum quantity of lime is added before an analysis is made, the error caused by the unsatisfactory composition of the relatively small quantity

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of extra lime will be of little importance, and no second analysis will be necessary. A chart or table, for determining the quantity of lime that must be added to the liquor in a causticizing tank of known volume, can readily be prepared by the mill chemist, for any causticity of the liquor, from the per cent of CaO in the lime and the cubic centimeters of standard acid neutralized by carbonate in the green liquor. (See Appendix to this Section.)

14. When a sulphate mill is first started, it is usual to prepare cooking liquor from soda ash, which is dissolved in water until a solution is obtained of 18°–20°Be. at 60°F. This liquor is then causticized with lime, and the caustic solution thus obtained is used for cooking. (The deficiency in total-liquor volume for the digester is covered with water in the first cook until some black liquor is obtained.) The first cooks will thus be soda cooks. When sufficient black liquor is obtained, the recovery room is started and as much salt cake is used as is advisable (not more than 500 pounds of salt cake per hour per firebox at good run). The liquor thus obtained will be sulphate white liquor proper. In a few cases only, the first white liquor is made to contain sodium sulphide, either by adding Na_2S or by dissolving sulphur in the caustic soda solution.

15. Effect of Concentration.—When the green liquor is treated with lime, the following reaction, which is never complete, takes place:

$$Na_2CO_3 + Ca(OH)_2 = 2NaOH + CaCO_3$$

The completeness of this reaction depends to a certain extent upon the concentration of the solution of the sodium carbonate and the ratio of the amount of sodium carbonate to the calcium hydrate $Ca(OH)_2$. While a weak solution of sodium carbonate, say one having a density of 7°Be. at 15°C., can be causticized as high as 99%, *i.e.* 99% of carbonate is changed to hydrate, it is impossible to reach a causticity of more than 95% with a solution of 19°Be. at 15°C. The reason for this is that with an increased concentration of sodium hydrate, the solubility of the calcium hydrate is decreased until, finally, there are not enough calcium ions in the solution to surpass the limit of the solubility of the calcium carbonate.

16. Effect of Sodium Carbonate.—The sodium carbonate in the white liquor is a dead load, having no value for the cooking process. In the cycle of operations, however, there are losses due

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to the sodium carbonate that are proportional to its concentration in the liquor. Thus, it is of great importance that the quantity of carbonate be kept as low as possible. By using a weak solution of liquor, a high degree of causticization can be maintained, with small losses of lime; but the solution must be strong enough to contain the quantity of alkali that is necessary for the cook in the volume of liquor wanted for the digester. The alkali will have to be reclaimed, however, which requires that the water be evaporated, and this evaporation is expensive. The cost of the evaporation of the extra water used to obtain the higher degree of causticity must be balanced against the saving due to the decrease of content of sodium carbonate. However, another factor must be considered, which, in a mill having the usual equipment of settling tanks, eliminates the matter of high causticity altogether, and this is the volume of sludge that results from the charge. This sludge, which always contains a considerable proportion of the white liquor, has to be washed, in order to reclaim the valuable alkali. The resulting wash water finds use in filling up the dissolving tanks for a new batch, and its volume is thus limited. The final inevitable loss of alkali in the sludge thus depends upon the quantity of sodium salts that remain in the first strong sludge, and this, in turn, depends upon the strength of the liquor and the volume of precipitate of calcium carbonate. To work with a weaker solution, will make the quantity of lime necessary to obtain a particular causticity smaller, and will thus give a smaller volume of sludge in the weaker liquor; but at the same time, it will decrease the strength of the cooking liquor, increase the work for the evaporators, and lessen the capacity of the liquor room. A decrease of the lime alone, without changing the strength of the green liquor, will decrease the quantity of sodium hydrate; at the same time, it will increase the content of non-active sodium carbonate and, with it, the losses of chemical, which are independent of the amount of lime used, in proportion to hydrate, if the percentage conversion of carbonate is decreased by using less lime. In the average mill having standard equipment, the most satisfactory results are obtained when the green liquor is taken from the dissolving tanks testing 18°–20°Be., hot, and a causticity of 75%–80% is maintained.

17. Washing the Sludge.—When the strong white liquor has settled and has been drawn off from the tank, there remains

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in the tank a certain volume of sludge containing a considerable quantity of sodium components, which often amount to 25% or more of the original liquor. In order to reclaim the valuable substances in this sludge, it must be washed with water. As mentioned before, the volume of this wash water is limited to the volume of the dissolving tank, because it will have to be used to make another charge of liquor. The actual washing is often preceded by a preliminary wash with a small amount of water or with weak wash water, and the resulting liquor is sent with the strong liquor to the digester room. This procedure permits the use of more wash water and, in addition, increases the capacity of the tank room, since the tank space is relieved of liquor from the first wash. An additional quantity of alkali is obtained from the same batch. This preliminary wash would, of course, require a little more time.

Care should be taken that all washes are of as nearly the same size as is possible and that the maximum volume of water is used in each case, in order to recover the greatest amount of chemicals from the sludge. Samples of sludge should be taken at regular intervals and analyzed for the amount of soda being lost, and this loss should be reduced to a minimum. There may be occasions when it is advisable to do all washing with water; but this method, though it gives a quick wash, is not common.

Another method is to use a series of washing tanks, thus: To the tank containing sludge most completely washed, add clear water and agitate. When this wash is settled, transport the clear liquor to a tank containing a sludge that has been washed one time less, proceeding in this manner until the entire number of washes has been obtained. Thus a tank that has never had any wash water in it is furnished with the clear liquor from a second (strongest) wash, and the sludge from this second wash is mixed with the liquor from the third wash; the sludge from the third wash is mixed with clear water or with liquor from another weaker wash. This procedure is very slow, and it calls for a great capacity of tank room. It must be remembered that before a tank is ready for a new charge, the sludge has to settle through a distance equal to five times (if 4 washes are used) the height (depth) of the tank—once for strong liquor and four times for the four washes. It is further to be noted that the final volume of weak liquor obtained is not sufficient to fill the dissolving tanks for a new batch, because the sludge always retains some liquid.

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18. If the size of the tank room permits, the best way to do the washing is to make the third and fourth wash with water, make each of them large enough to give half a tank of wash liquor, and then use this liquor for making up the first and second washes. If there is a separate storage tank, in which the last two washes can be mixed and from which wash can be drawn for the first or second wash whenever needed, there will be no delay on account of one tank waiting for another; but, even if this should not be the case, there will not be many instances of delay, because there is always some of the liquor settled in the tanks containing the last washes, with which to make up another wash. Washing thus conducted will give very satisfactory results, and should reduce losses of chemicals in the liquor room to a quantity corresponding to 40–50 pounds of salt cake per ton of pulp.

19. Filter Presses.—Filter presses are employed to reclaim as much as possible of the valuable chemicals in the lime sludge. When a filter press is used, the process of washing the sludge is usually as follows: The causticizing tank is made up as usual and causticized, and the sludge is allowed to settle. The strong liquor is then drawn off to the white liquor storage. The wash from the filter press is run into the tank, and the agitator is started. The contents is allowed to settle, and the clear liquor is pumped to the dissolving tanks. The tank is then filled approximately half full with water; it is agitated, and the contents is dumped or is drawn off by gravity to the slurry tank. The slurry tank contains a rather heavy concentration of sludge, and from this tank, the sludge or slurry is pumped to the filter press for a time, to deposit a sufficiently thick cake. The pump is then connected to a hot-water tank, and the cake of sludge is washed with hot water in the press. When the filtrate tests 0°Be., the cake of sludge is said to be sufficiently washed. The filter press is then opened and the press cake is discharged into cars or conveyors, the disposal of this depending on the use to which the plant desires to put it.

In case a continuous filter is used, the deposit from washing and the removal of the cake go on without interruption.

A brief description of one press of the first type will be given here; but it is to be noted that there is still room for its improvement and for adapting it to the work required of it.

Fig. 3 shows a leaf type of filter press. Here the casing *a*,

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approximately cylindrical, is divided in halves by a horizontal plane passed through the axis. The two halves are connected by the ring *b* and are drawn tightly together by the bolts *c* and eccentric shafts *d*. The filter leaves *e* are hung from the top of upper half of the case. These may consist of a ring of pipe *f*, perforated or slit around the inside and covered with a filter cloth *g*, which is prevented from collapsing by struts *h* that are braced by pins *i*. The distance between the leaves depends on the character of the material filtered. A dense, non-porous material requires leaves close together.

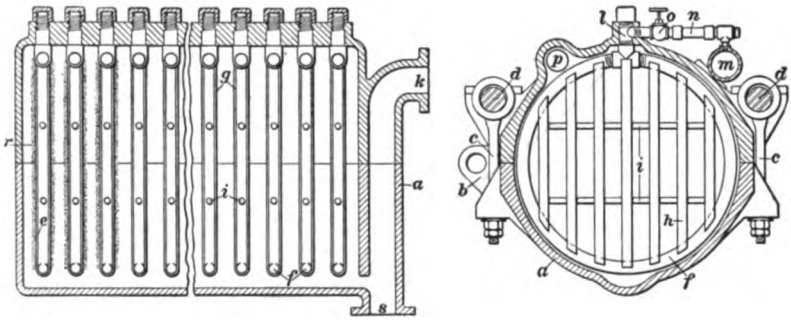

FIG. 3.

In operation, the sludge enters at *k*, under pressure, and the liquid filters through cloths *e*, passes into frame pipe *f*, through nipple valve *l*, to discharge channel *m*. A sight glass is inserted at *n*, so that should the cloth brake, valves *o* can be closed and, filtration continued. Wash water may be introduced at *p*, and this may be followed by air, if desired, to dry the layer of sludge that has been deposited at *r* on the outside of the cloth. The cake may be washed out at *s* by forcing the water back into the filter leaves; or the bottom half of the case may be dropped, and the cake delivered to a truck or conveyor.

Another type of leaf filter press has a nest of long rectangular leaves, which are introduced through the end of a long horizontal cylinder. The principle is the same as for the one described.

A continuous filter is described and illustrated in the Section on Soda Pulp.

20. Care of Filter Press.—The principal trouble has been, and still is, to find a filter medium that will resist the severe action of the liquor. Insofar as the writer is aware, no filter has yet

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been operated successfully on strong liquor; even after the strong liquor has been drawn off and the tank furnished with water before the sludge is taken on the filter, the action of the rather weak liquor thus obtained necessitates a frequent changing of the cotton cloths that generally are used as filtering cover in the modern mechanical filters. It may be remarked, however, that a patented rubberized fabric holds considerable promise as a filter cover. The sludge, however, can be washed perfectly clean from soluble chemicals with a very small quantity of water. Wire cloth made from Monel metal has also been used as a cover on filter leaves. The writer knows of one case in which a filter press thus equipped worked very successfully for a short period. A successful filter press would be a welcome addition to the machinery of the sulphate mill; because it has great capacity, gives a perfectly clear liquor under all conditions, makes it possible to get a high causticity, gives a large volume of strong liquor and scarcely any weak liquor, and produces a sludge that is practically free from soluble alkali. The quantity of steam used in causticizing the liquor is far less; in fact, the steam might be replaced entirely by prolonged agitation, and only a small volume of hot water is required for the washing in the press. The tank room may then be just large enough to take the liquor in, as space is required only for the causticizing tanks and filter presses. The washing is done in the filter, after the first strong liquor is settled and drawn off.

21. The Filter Box.—Another type of filter consists of a wide and shallow wooden box, which has a perforated sloping bottom and underneath that, a horizontal solid bottom. The perforated bottom is sometimes omitted. A drain pipe at the lower end of the sloping bottom serves as an outlet. The filter medium consists of a layer of gravel, on top of which is placed a layer of finer gravel or sand, and then a layer of sawdust, which is protected by a grating or perforated plate. This filter is used for the sludge after the last wash, for the purpose of draining off as much of the wash water as is possible. The sludge that remains in the tank after the washing is finished, is agitated with a small quantity of water and dumped into the filter, where it is left to drain until the lime sludge shows cracks on the surface. The sludge then contains about 55% moisture; and sludge that has been washed four times, twice with weak liquor and twice with water, will contain less than 2% sodium oxide in dry sludge.

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22. Disposal of Sludge.—In mills where it is not possible to dispose of the lime sludge in a river, it is often a serious problem how to get rid of the sludge. To reclaim the lime for use in the liquor room has not as yet become a general success, although at least one plant is recovering the lime by calcining (burning) the carbonate sludge—$CaCO_3 = CaO + CO_2$. It is necessary to add 15 % new lime to make up for losses and to counteract the accumulation of impurities. The impurities that come from the smelter lining ruin the lime for pulp making, and the settling properties of the lime are adversely affected by such impurities as aluminum and magnesium. When so treated, the lime sludge is drained on a sand filter, or taken from the filter press, and then shoveled into a conveyor, which feeds it into a rotary furnace of the type used in cement making,—similar to that shown in Fig. 23 at *B*, but about 100 feet long, and which is heated with producer gas or powdered coal that is blown directly into the furnace. The regenerated quick lime has a brownish color, and comes out in balls varying from the size of a pea to that of one's fist. The recovered product is not so good from sulphate-mill sludge as that recovered from a soda mill.

However, a use has been found for the sludge in the manufacture of a special brick for building purposes. Another purpose for which lime sludge has been employed to good advantage, is as a fertilizer for soils that are deficient in lime. Certain precautions must be taken, however; and if transported considerable distances, the lime sludge must first be dried. Dry and pulverized lime sludge has also found a use in glass manufacturing.

23. In conclusion, it may be remarked that the liquor room is a very important part of the sulphate pulp mill; the work there should be carefully controlled and supervised, as so much depends upon this department being properly conducted. The next department of the plant, in order of operation, is the digester room, which will now be considered.

QUESTIONS

(1) Name the principal operations in a sulphate-pulp mill.

(2) What alkaline process other than the sulphate process is used for cooking wood? how do the two processes compare as regards yield?

(3) Mention the character and uses of sulphate fiber; why is it sometimes called kraft?

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(4) What takes place in the liquor room?

(5) Mention the qualities of a good lime; how much is required per ton of pulp?

(6) What is meant by green liquor? Name its principal constituents.

THE DIGESTER ROOM

THE THEORY OF COOKING

24. Composition of Wood.—Wood is composed of *cellulose fiber* and *lignin* (also called ligno-cellulose), with varying amounts of other organic substances of more or less acid nature, and a very small percentage of inorganic substances. The ash (inorganic) content of spruce wood, for instance, is only 0.3%.

The principal solid constituents of spruce, according to Klason, were given in the Section on *Chemistry*, but the table is here repeated, and it will be noted that approximately 50% of the

Spruce	Cellulose	53%
	Lignin	29%
	Other carbohydrates	13%
	Resins, fats, etc	4%
	Albuminates	1%

dry weight of wood is cellulose.

25. Purpose of Cooking.—In any chemical process for manufacturing wood pulp, the object of the digesting, or cooking, process is: 1st, in the case of easy bleaching pulp, to destroy the non-cellulose constituents of the wood (pentose, etc.) as completely as possible; 2d, in the case of kraft pulp, to cook the wood just enough to obtain a fiber that may be readily separated. Some loss of cellulose, however, cannot be avoided, and the purer the resulting fiber the greater is the loss. For pulping wood, either an acid treatment (as in the sulphite process) or an alkali treatment (as in the soda and the sulphate processes) is used. In the soda process, the cooking liquor is mainly composed of sodium hydrate, while in the sulphate process, a mixture of sodium hydrate and sodium sulphide is used as a solvent for the undesired wood substances. The action of the liquor on the wood and the chemical reactions that take place in the digester, are very much the same in the two processes, since, in both cases,

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the sodium hydrate chiefly governs the procedure; but the qualities of the resulting fiber are quite different.

26. Reactions in Digester.—According to our present knowledge, the nature of the reactions in the digester is an oxidation or hydrolysis (see Art. **27**) of the lignin and carbohydrates. The resulting organic substances of an acid nature are later neutralized by the sodium hydrate, and the resulting salts are soluble either in water or in an excess of alkali. Fats and resinous substances are saponified, and are dissolved or carried in suspension in the liquor. The complicated molecule of lignin is partly hydrolyzed, which increases the possibilities of splitting up the lignin molecule into smaller molecules that are soluble in alkali. Wood alcohol, which is formed in considerable quantities during the cooking (26 pounds per ton of pulp according to Bergstrom and Fagerlind), is derived from the hydrolysis of the lignin.

Klason's research work indicated that the smallest quantity of active alkali (figured as NaOH) that will result in removal of all the non-cellulose matters in the wood is 20% of the dry weight of the wood; but he adds that this quantity will never suffice to carry through the perfect pulping of the wood, owing to the fact that a complete utilization of the alkali can never be obtained. His analyses show that about 40% of the alkali necessary to use in order to obtain an easy-bleaching pulp is left in the resulting black liquor as free hydrate or is so loosely engaged that it will combine with carbonic acid. From these results, he concludes that part of the alkali has to be used as a solvent for the organic sodium salts that are formed during the cooking. A further reaction of the alkali would lead to a precipitation on the fiber of the organic substances, which would form a protective covering. The fact that the alkali is thus engaged explains why the cellulose is not destroyed through the action of the excessive alkali. A solution of sodium hydrate, of 6°Be. will, according to Tauss, bring in solution 20.28% of cellulose that has been exposed to its action for three hours under a pressure of 150 lb. per sq. in. These are conditions that are often actually reached at the end of a cook; but even a very much delayed discharging of the digester would not lead in actual mill practice to a loss of cellulose nearly as great as the figure quoted.

The composition of the dry substances of the black liquor of 1.1166 sp. gr. in grams per liter from a soda cook is given by Klason as follows:

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Na_2SO_4			6.7 g.
NaCl			2.0 g.
Na_2CO_3			9.3 g.
NaOH free or loosely engaged			41.5 g.
NaOH neutralized by the following acids:			27.2 g.
Formic and acetic acids	11.5 g. engaged	9.8 g.	
Lactic acid	49.0 g. engaged	10.9 g.	
Phenols, fats, and resinous acids	30.0 g. engaged	6.5 g.	
Lignin	53.0 g. engaged		
$NaOH$ neutralized by CO_2			3.3 g.
Total NaOH			72.0 g.

From repeated experiments, Klason learned that when the free alkali in the black liquor (found by determining the quantity of CO_2 the black liquor will absorb) exceeds 40% of the original quantity of active alkali, the result will be considerable losses of cellulose. In the analysis just given, there was $\frac{41.5}{72} \times 100 = 59\%$ of free alkali in the total NaOH.

27. Composition of Liquor in Sulphate Process.—The cooking liquor of the sulphate process differs from that of the soda process in its composition, in that the active alkali in the former is a mixture of sodium hydrate and sodium sulphide. It is acknowledged that sulphur dissolved in the soda liquor, even in small quantities, will improve the quality of the fiber to a certain extent and increase the yield. The fact that the presence of sulphur in the digester does improve the yield of the soda cook is credited to a reducing atmosphere that is created in the digester by the sodium sulphide.

Prof. Klason has also studied the reactions that take place in the sulphate digester, and he has found that the reactions are along very much the same lines as in the soda process. As in the soda cook, the solvent that acts on the wood in the sulphate process is sodium hydrate. The sodium sulphide in solution is partly hydrolyzed into sodium hydrate and sodium sulph-hydrate, thus

$$Na_2S + H_2O = Na_2S + HOH \rightleftarrows NaOH + NaSH$$

The reaction represented by the foregoing equation is called a **double decomposition,** the metal of the salt changing places with the hydrogen of the water, both substances, the salt and the water, being decomposed. This reaction is reversible, and the direction is determined by the relative concentration of the sub-

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stances on either side of the equation. A double decomposition in which water is one of the reacting compounds is termed **hydrolysis,** and the salt is said to be **hydrolyzed.** A **sulph-hydrate** is formed when S is substituted for O in the hydroxyl; thus, the formula for sodium hydrate is NaOH; substituting S for O in the hydroxyl OH, sodium sulph-hydrate NaSH is formed.

Referring again to the reactions in the sulphate process, the sodium sulphide as such is thought to have no influence whatever on the wood. As the hydrolysis proceeds and the sulphide becomes available as hydrate, the hydrate becomes active and combines with the acids that result from the decomposition of the lignin. The other member that results from the hydrolysis of the sulphide, the sulph-hydrate, can combine with the alcohols and phenols as well as the hydrate itself, and is better adapted to this purpose because of its weaker affinities. Thus the sodium sulphide becomes available as active alkali only in the ratio that it is used up; and it is Klason's opinion that the protective effects produced by the sulphide on the fiber are due to this property. How the sulphur is disposed of in the process, Klason shows by he following figures:

Engaged by lignin	51.8%
Engaged by volatile organic substances	15.0%
Engaged as sodium sulphide	15.8%
Not accounted for	17.4%
	100.0%

The large quantity of sulphur not accounted for has very likely become oxidized to sulphate during the cooking.

28. Cause of Bad Odors.—The bad odors about a sulphate-pulp mill are due to the formation of methyl mercaptan CH_3SH and, to a smaller extent, to methyl sulphide $(CH_3)_2S$, both of which, as well as wood alcohol, are derived from the lignin through hydrolysis. A **mercaptan** is a compound that is derived from an alcohol by the substitution of S for O in the hydroxyl; thus, the formula for methyl alcohol is CH_3OH, and the formula for methyl mercaptan is CH_3SH. In the presence of an excess of alkali, as when cooking easy-bleaching pulp, the odors are less perceptible, because the excess of alkali facilitates the formation of the less odorous methyl sulphide. The methyl mercaptan,

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which in the presence of alkali is of a weak acid nature, gives with excess sodium hydrate, sodium mercaptide, CH_3SNa, from which compound the methyl sulphide can be obtained in two ways, as indicated by the following equations, in which R is some organic radical:

$$CH_3SNa + CH_3OR = NaOR + (CH_3)_2S$$
$$2CH_3SNa = (CH_3)_2S + Na_2S$$

29. It is estimated that when cooking easy-bleaching pulp, there is formed about 220 grams of methyl mercaptan per metric ton (2204.6 lb.) of pulp, but that the quantity can be ten times as large when the amount of alkali used is not sufficient to dissolve all the lignin in the wood. Of course, the quantity of methyl mercaptan also depends upon the amount of sodium sulphide that is present in the liquor and upon the constitution of the lignin. Thus, under the same conditions, pine is said to give twice as much methyl mercaptan as spruce.

The organic substances found in the black liquor from sulphate liquor are also given by Klason & Segerfelt, and the analyses agree quite closely with those from the soda process, as shown by the following table:

	Sulphate Process		Soda Process
Lignin	542.9	grams	585 grams
Acids of fats and phenols	24.7		
Formic acid	36.9	grams	77 grams
Acetic acid	51.6		
Lactic acid	303.4	grams	326 grams

OPERATION OF DIGESTER ROOM

30. Treatment of Chips.—Chips from the wood room are treated under steam pressure with a certain quantity of active alkali, forming a part of a certain volume of liquor, contained in a closed steel or wrought-iron tank, called a **digester,** where the liquor is by some means heated to a certain temperature. This treatment brings the non-cellulose materials in the wood into solution, and the cellulose fiber that makes up about 50% of the wood substance is freed.

Close attention should be given to the definition of the following terms, which will be frequently used hereafter:

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Active alkali: the sum of the sodium hydrate and sodium sulphide figured as NaOH, or as Na_2O, according to the practice of the mill.

Total active alkali: the number of pounds of active alkali used per charge.

Total liquor: the volume of liquid used per charge.

31. The Digesters.—The digesters in the sulphate process are, as previously mentioned, made from steel or wrought-iron plates, either material giving equally good service. They are of different shapes and sizes, but the tendency is toward a larger unit. The large digester gives less work in the digester room; it is more economical in steam consumption than one of smaller size, because it offers less surface per unit of volume, and thus lessens the losses of heat due to radiation. In spite of the steam economy that is derived from the use of a big digester, it is not advisable to let more than one-third of the output of a mill depend on one unit, if it can be avoided without going outside of standard equipment, for the reason that if it were necessary to shut down the digester, too much of the mill production would then be tied up.

Digesters are either riveted or welded; the welded form is to be preferred, as it is often difficult to keep riveted digesters from leaking, which is generally due to inferior shop work. Since the cooking liquor has little corrosive action on the iron or steel, no lining is necessary, as is the case with digesters used in the sulphite process.

32. The outside of the digester should be carefully insulated with some non-heat-conducting material. It is estimated that digesters not so protected will lose by radiation approximately 3 B.t.u. per square foot per hour per degree Fahrenheit difference in temperature between inside and outside the shell of the digester (that is, under ordinary conditions, about .6 lb. of steam will be condensed to water, and the heat so liberated will be radiated), and that a cover of magnesia or asbestos will reduce these losses about 85%. To assure good service from the insulating covering, it should be put on in sections that can be easily removed, in case of leakage in the shell. The insulating covering should, in turn, be protected with some water-proof cloth—tarred jute will give good service—in order that the digester may be washed off and kept clean.

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Figs. 4 and 6 show two forms of digester (described in detail later). *B* is an opening for charging with chips and liquor, *D* is an inlet for steam, and *E* is an outlet for relief of air, gas, and steam. At the bottom of the digester *A* is an opening *F* for discharging the pulp. An asbestos-packed, extra-heavy, plug cock *G*, Fig. 6, is used to shut off the discharge pipe. To avoid putting the strain on the plug cock that would be caused by a lever, it should be operated by means of a worm gear and hand wheel. The plug cock has a long life and, if leaky, can easily be repacked, while a seated valve, unless furnished with an opening for washing out completely, will never give good service, pulp and chips are always liable to keep such a valve from shutting off tight. The same trouble is likely to affect the working of a gate valve, where the bonnet can get filled with pulp, the bonnet being the chamber into which the gate is drawn when the valve is opened. If a gate valve be used, its operation will be improved by having a black liquor or water line on the bonnet, to wash out, after each operation, the stock which accumulates there.

There are two types of digesters—the vertical rotary digester and the vertical stationary digester. The horizontal rotary digester is very seldom used for making sulphate pulp, because of the trouble it gives in charging the cook.

33. Rotary Digesters.—The **vertical rotary digester,** *A*, Fig. 4, generally has a capacity of from 2 to 2.5 tons of kraft pulp, air-dry basis, per charge. Both ends are cone-shaped, the elements of the cone making an angle of 45° with the axis, thus making the total angle of the cone 90°. A cast-steel neck *H* is riveted or welded to the top end, to which a cover *I* is bolted with easily-removed, swing bolts *K*. The digester is charged through this opening. At the bottom of the digester, is an outlet *F*, about 6 in. in diameter, for the discharge of the pulp. The trunnions *L*, which support the digester and around which it revolves, rest in strong bearings *M*, supported on a rigid foundation *N*. The steam pipe *D* is continued up the inside of the digester, and is connected up with a perforated steam coil *O*, placed as high as possible and supported on the shell. The total area of the perforations in the coil should be equal to the area of the cross section of the pipe. It is important to protect all parts of the digester from the wearing effects of the rushing steam, which are considerable and may cause an accident; therefore, the perforations should be so drilled that the steam

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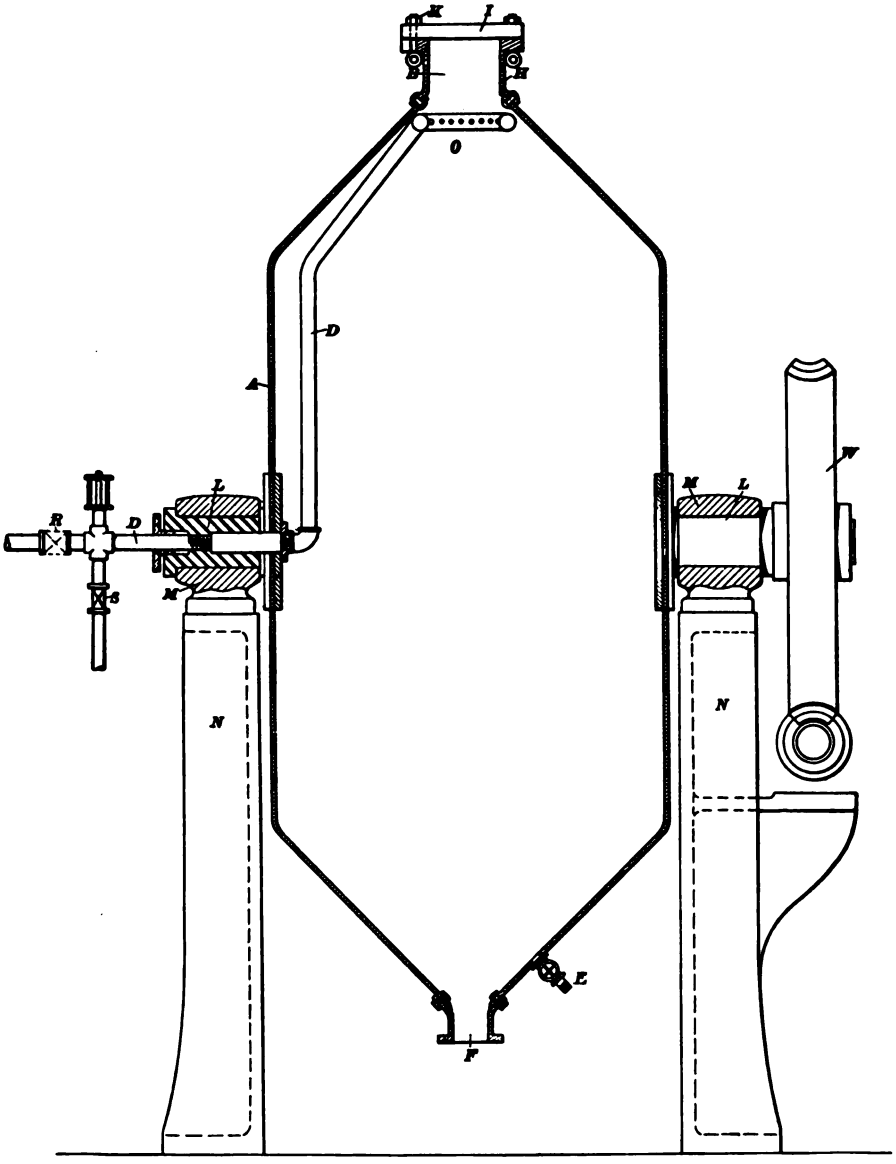

FIG. 4.

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will not impinge directly on the shell. The cock *E*, which serves the double purpose of sampling valve and as relief valve for air and turpentine in the early stages of the cook, is supplied with a nipple for connection with a steam hose attached to a pipe line, to carry the gas outside the digester room. This cock is located near the bottom of the digester, to make certain that no liquor will be pulled out when air, etc., are gassed off. It is then at the uppermost position, the digester being in a reversed position from that shown in the figure.

The digester makes a revolution in from 8 to 12 minutes, the turning being effected by a worm-gear arrangement *W*, which is either directly connected to a motor or is belt driven. The joints in the trunnions must be watched for leaks, and must be re-packed frequently.

34. The strong features of the rotary digester are perfect circulation, which gives a uniform grade of pulp, and the better heat economy. The saving of steam is due to the smaller volume of total liquor, which can be kept down to 25%–30% of the digester volume, and to the fact that no steam is relieved during the cooking, to create circulation in the digester; also, there will be less evaporation to be done later in the process, when the liquor is reclaimed, owing to this smaller condensation of steam in the digester. The weak points are: more complicated handling of the cooking; more trouble in keeping the steam joints tight; also, the large amount of floor space occupied by a unit.

35. When the digester is to be charged, it is brought to the upright position shown in Fig. 4, the cover *I* on the manhole is taken off, chips are run in from the bin above, and with them, at the same time, the white liquor necessary for cooking. Should the volume of white liquor that is necessary to give the quantity of alkali called for be too small to give proper circulation, black liquor is used to make up the required volume of total liquor. By running chips and liquor into the digester simultaneously, not only is the time for charging the digester reduced but it also effects a better packing of the chips (which should fill the digester), and the final result is a bigger charge, that is, the yield per digester becomes greater. It is to be noted that dry wood requires more liquor than wet wood.

When the digester is charged, the cover *I* is bolted on tight; a sheet of wet pulp makes an excellent packing for this purpose.

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The digester is then turned half a revolution and left with the steam coil down. The hose on the relief-pipe line is connected up to the cock *E*, which is now at the top, and which is opened. Steam is then turned on the digester, through the line *D* and coil *O*. With several digesters in one room, particularly where no condenser is used for taking care of the steam that is relieved from a digester prior to blowing, the relief steam can be used to advantage for starting off a new cook. In such case, the valve *R* is opened up, this being the connection with the main relief line. The steaming is continued by opening the valve *S*, the valve *R* now being closed. During this period of the cook, a considerable quantity of turpentine that is in the wood is driven off, which may be recovered by passing the gases escaping through the cock *E* through a condenser. When a pressure of about 80 lb. has been reached in the digester, the cock *E* is closed, the hose is disconnected, and the digester is revolved, with the steam valve *S* open, until cooking pressure (about 100–112 lb. and a corresponding temperature of 338°–345°F.) is reached; after which, only steam sufficient to maintain this pressure is admitted. The digester is kept revolving until, in the judgment of the operator, the charge is nearly ready to blow, when he stops it, with the plug cock *E* down. The quality of the pulp in the digester is controlled by taking a sample of the charge through this cock *E*. Should the charge prove not to be ready, the digester is turned over again until it is again judged to be ready. Should a new sample show a result that is satisfactory, the digester is connected up for blowing, and, in the meantime, the pressure is relieved by opening the valve *R*, *S* being closed. The coil *O* is now at the top and is well above the level of the charge; so the danger of pulling over liquor and pulp is very slight. This relief steam is used either for starting another charge (as previously mentioned) or is condensed in a water heater (Art. **43**). The relieving of the pressure takes from 10–30 minutes, according to conditions. The relieving of pressure, though not absolutely essential, should be performed if for no other reason than to save the diffuser bottoms and to prevent blowing over so much stock out of the diffuser. If the relief steam be let into a condenser (Art. **43**), the heat of condensation can be used for the purpose of pre-heating water for different places in the mill.

When the blowing pressure, about 80 lb., is reached, the digester is revolved once more, to obtain a uniform mixture and to

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facilitate the complete emptying of the charge. When again in upright position, the digester is connected to a pipe line, through which its contents are discharged, on opening valve *F*, into the tank or diffuser that is used for this purpose.

36. Fig. 5 is a diagram showing the relation of the pressure to the time of cooking for a rotary digester which was relieved in 2 stages, and rotated between reliefs. The broken line, called the *steaming curve*, shows at a glance all the various steps just

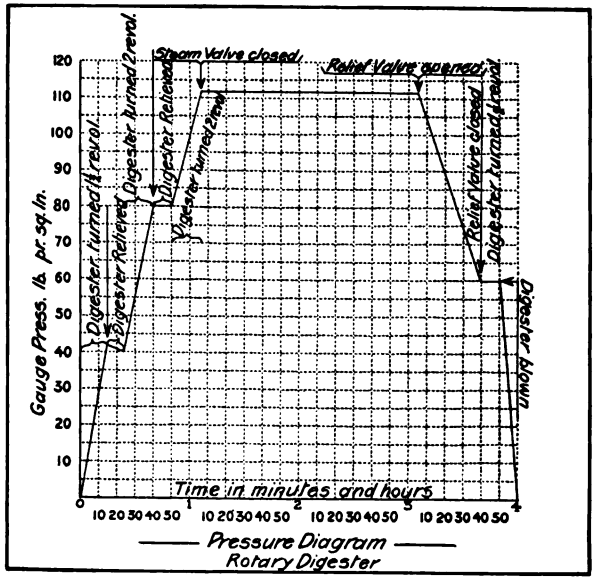

FIG. 5.

described. It will be observed that at the end of about 15 minutes, the pressure has reached about 42 or 43 pounds; during this time the digester has completed $1\frac{1}{2}$ revolutions. The digester is then stopped and received for about 10 minutes and the pressure falls slightly to 40 pounds. The digester is then revolved and the steaming is continued until a pressure of 80 pounds is reached, which takes 15 minutes more and makes the total elapsed time 40 minutes. The remaining steps are clearly indicated on the diagram. The procedure illustrated in the diagram is a variation of the operation as described in Art. **35.**

37. Stationary Digesters.—The equipment of the stationary digester is very similar to that of the rotary digester, the chief

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difference being in the location of the various inlets and outlets. The ends of the stationary digester are either both conical or the bottom is conical and the top is dish shaped or both ends are dish shaped. Fig. 6 shows a stationary digester having a conical bottom and with the top dish shaped. The objection to a dish-shaped bottom is that it gives more trouble in blowing than a conical bottom. The majority of the stationary digesters used in the United States and Canada are smaller in diameter in proportion to the height than is the case with the rotary digesters.

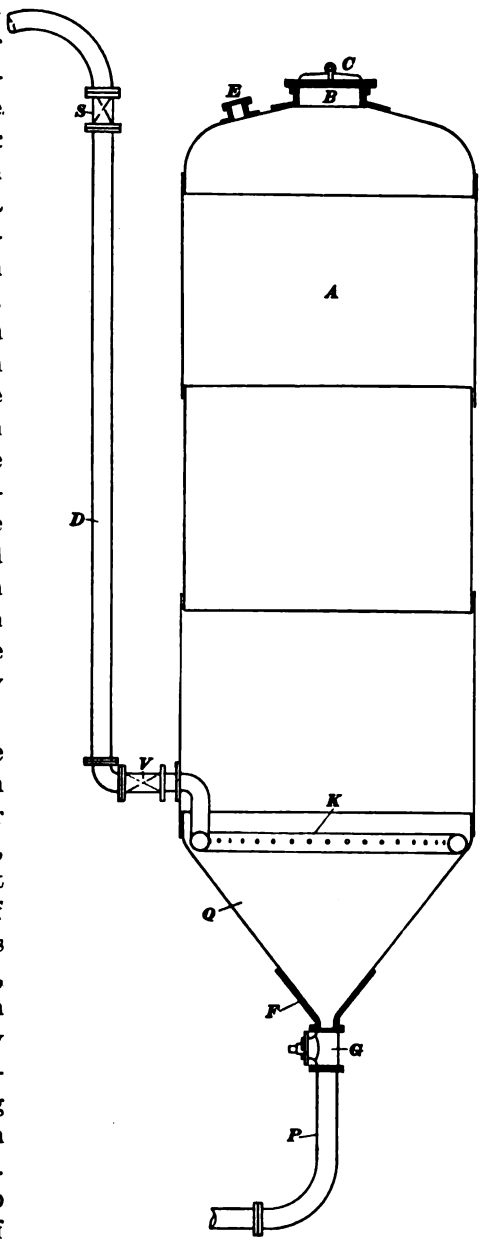

FIG. 6.

38. In addition to the manhole *B*, fitted with cover *C*, Fig. 6, for charging the digester, there is an opening *E* at the top for relieving of gas and pressure. This opening, or outlet, should be placed as high as is possible, preferably in the neck of the digester, to avoid pulling over the liquor when the digester is relieved. A strainer prevents pulp from entering the relief line. In the early stage

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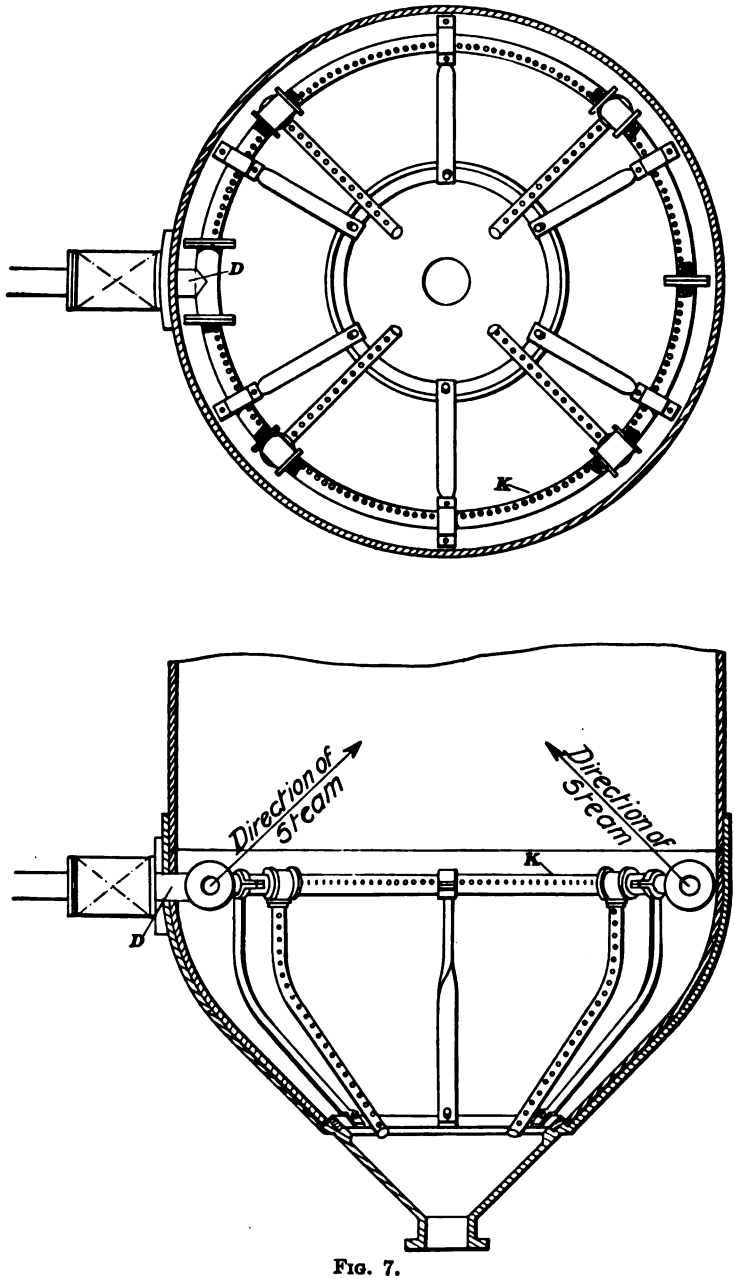

Fig. 7.

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of the cook, when the liquor in the digester is still rich in active alkali, and when most of the relieving occurs, the pulling over of a certain volume of the liquor might mean such big losses of alkali as to affect the quality of the pulp. Some digesters are so constructed that the relief valve is placed on the cover *C* of the top manhole. Although this arrangement is correct in principle, it gives trouble when taking the cover off. In the case that the relief pipe should plug up, a small live-steam connection should be provided on the relief line between the valve and the digester, to allow the obstruction to be blown back and clear the pipe.

The steam is let into the digester through a coil *K* in the bottom. Another good way to arrange this coil is shown in Fig. 7. This method insures cooking of the chips in the cone and may help to maintain circulation, as it gives additional heat to the liquor in the center of the digester. The size of the perforations ($\frac{1}{16}$-inch holes, in this case) and their number must be such that they will deliver up to the capacity of the steam pipe *D*, and the steam pipe should be large enough to supply a sufficient quantity of steam within the time allowed for steaming the digester. For a digester holding 1400 cubic feet, a 3-inch steam pipe is sufficiently large.

The blow valve *G*, Fig. 6, is of the same type as for the rotary digester. The discharge (blow) line *P* is from 6 to 8 inches in diameter, according to the size of the digester. A 6-inch blow line will empty a 1400-cubic-foot digester, blown at an initial pressure of 80 pounds, in about 15 minutes. The operation of blowing the stationary digester can be made much simpler than blowing the rotary digester, since all the connections can be made permanent.

39. The digester is mounted on heavy cast-iron, steel, or concrete columns, and should be at a higher level than the floor, to make it easily accessible for operating the blow valve and for changing it.

On the main steam line *D*, Fig. 6, going to the digester, should be a steam valve *S*. A check valve *V* should also be placed on each individual digester, to prevent liquor from going back to the steam boilers or to other digesters, in case the boiler pressure should drop below the pressure in the digester. If the steam pressure is much higher than the cooking pressure, a reducing valve ought to be placed in the main steam line to the digester

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room; and if saturated steam (*i.e.*, if the steam is not superheated) is used, there should also be a steam separator on the line, close to the digesters, to keep the steam as dry as possible.

40. A good arrangement is to have the digesters and a dummy connected to the same blow line. Check valves are put between the digesters and the main pipe, to keep stock from coming back into one digester pipe line when another is blown. Also, when stock is blown from a digester to a diffuser, the solids or liquid matter in steam from the diffuser are trapped, first, in a receiver or steam separator and, second, in the dummy mentioned. When steam is relieved from a digester, solids and liquid matter are trapped in the dummy, and the steam goes from the dummy to a condenser or to the atmosphere. Stock and liquid caught in the dummy is blown back through the digester blow line into a diffuser, as may be necessary.

41. Operation of Stationary Digester.—The operation of the rotary digester was previously described in detail; the stationary digester is more easily operated and gives less work in the digester room. As soon as the digester is charged and the steam turned on, all the cook has to do is to observe his pressure gauge and take care that he relieve the digester without pulling out any liquor. Since the relief is the only means of obtaining circulation, the chances are that the cook will relieve more steam than is really essential to get uniform pulp. A steam-flow meter on the digester-room steam line puts a means of control into the hands of the superintendent; at the same time, it serves as a guide for the digester man. The steam should be supplied to the digester fast enough to bring the charge to the cooking pressure and temperature within a time not to exceed one-third of the total time used for cooking. While coming up to cooking pressure, the relief valve *E* is operated as described in Art. **35.** Thus, if the total cooking time is 4 hours (= 240 minutes), the cooking pressure should be reached in not more than $240 \div 3 = 80$ minutes. This applies to the cooking of kraft pulp. Sometimes, however, it will greatly improve the quality of the fiber if the time for steaming is prolonged. In case the wood is not uniform (for instance, wet and dry wood mixed), a longer time for reaching a pressure of 80 lb., below which pressure, no marked action of the liquor on the wood takes place, gives the mixed ships a better chance to be uniformly cooked.

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When the digester pressure is reached, the relief valve *E*, Fig. 6, is shut tight, provided good circulation has been maintained, and the steam valve *S* is left open just enough to keep up the digester pressure; that is, sufficient steam is admitted to make up for heat losses due to radiation. After the digester has been kept under pressure until the decomposition of the wood has reached nearly the point aimed for, near enough to finish the work by the time the digester is ready for blowing, the pressure is relieved down to

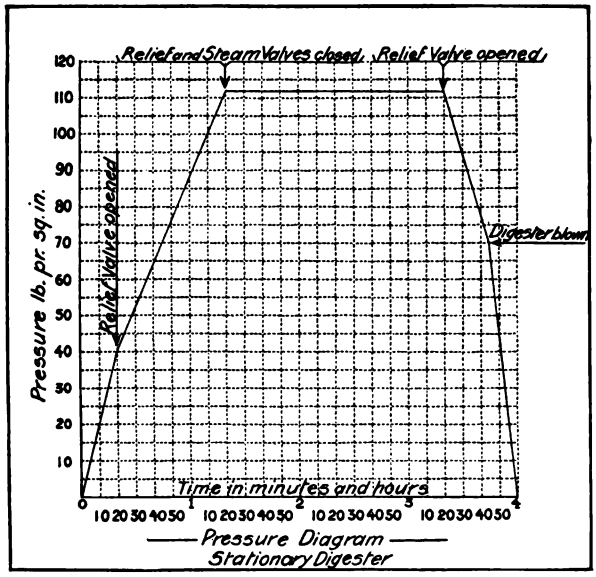

FIG. 8.

blowing pressure, about 80 lb. per sq. in., and the digester is then emptied in the same manner as was the rotary digester. In case the digester does not blow clean, that is, if some pulp is left in the digester, the digester should be reblown. To do this, sufficient black liquor is run in to cover the stock that is left, the cover is bolted on, and the digester is steamed in the ordinary way, with the steam valve wide open, to give a good stirring effect. The pressure is brought up to 70–80 lb., and the digester is discharged in the usual manner into the same diffuser as the previous part of the cook. To make sure the digester has blown empty, a light should be dropped in after each blow. Should it occur repeatedly that part of the charge is left in a digester, an improve-

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ment may result if the digester is first relieved to 10–15 lb. below the blowing pressure, and then steam is turned on, with the steam valve wide open, until the blowing pressure is reached. Care must be taken that this pressure is not exceeded. The same stirring effect, though not so thorough, will be obtained if a steam puff be shot into the digester after the blow valve has been opened. For this purpose a steam inlet is sometimes provided well down in the cone, as at *F*, Fig. 6.

A pressure diagram for a stationary digester is given in Fig. 8. It is interesting to compare this with the diagram for the rotary digester given in Fig. 5.

The pressure of the digester should be relieved as far down as time will permit and without risking the possibility that the digester will not blow clean. In addition to the economy due to the heat that can be reclaimed, there will be less strain in the blow lines and on the diffuser bottoms.

When easy-bleaching sulphate pulp is manufactured, the steaming should be done more slowly, which will produce better fiber.

It is most important that the cooking of a digester charge be begun right, especially with stationary digesters; for, upon a correct start—correct charge, volume and strength of liquor, steam pressure, careful relieving, etc.—uniform cooking depends.

42. Storage for Chips.—The digester room is also equipped with a chip bin for storing the chips; but if not so equipped, conveying machinery of very large capacity is required. The chip bin should be placed above the digester, so the chips may fall into the digester by gravity and make the time of charging as short as possible. The chip bin should preferably have a capacity for a 14-hour run, that the wood room may be operated in day time only, with a margin of time in case something should go wrong with the chip conveyors or in the wood room. A separate chip bin on a lower elevation and equipped with its individual elevating machinery, can take the place of an extensive storage above the digesters and will, in case of digesters of large capacity, save the building of an expensive superstructure. In a mild climate, where it is not a question of protecting the machinery from cold weather, it might prove economical simply to put up a light construction around the digesters and keep the main chip bin on the ground.

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43. White- and Black-Liquor Storage Tanks.—The digester room is also supplied with storage tanks for white and black liquor, though many mills prefer to have the black-liquor tanks in the evaporator building. These tanks are placed above the digester, and at a level high enough to permit the liquor to run into the digester by gravity in the time necessary to charge it with chips. The tanks should be large enough to hold all the liquor for one charge, which will have to be measured in these tanks; therefore, there is always a scale (graduated in inches or cubic feet) attached to the tanks. The white liquor for each charge should be tested chemically. (See Art. **12.**) That the measuring may be as accurate as possible, the cross-sectional area of the tank should be a small as the height of the room permits, for a tank of required capacity. A mistake of an inch in depth in the case of a tank of large diameter, especially when the liquor is strong, means a rather large quantity of active alkali, and it might affect the quality of the cook. For example, for a tank 8 ft. in diameter, every inch of depth represents about 4.2 cu. ft., while in the case of a tank 6 ft. in diameter, every inch of depth represents only about 2.4 cu. ft. Besides, there is a certain saving of liquor when using a tank of smaller diameter, since the scale is more sensitive, and errors due to forced increases for the purpose of making the reading in even inches (instead of inches and fractions) when figuring the charging table, will mean less unessential liquor added.

The white liquor measuring tanks should have the outlet placed well above the bottom; this will provide a space for lime sludge, etc. to settle in, and only clear liquor will then go to the digesters. Through another outlet in the bottom, which is connected with the liquor room, the tank can be washed out without any loss of alkali.

44. Condensers.—In the case of stationary digesters, the need of a condenser to take care of the heat that is contained in the steam and gases relieved from the digester is much greater than when a rotary digester is used, because in the former all the agitation, the circulation of the liquor in the digester, is maintained by relieving off steam. The quantity of steam thus used to obtain circulation is considerable, even in the most favorable case, and it may easily become unnecessarily large, through carelessness on the part of the cook. In his endeavor to obtain a uniform cook (result of digestion), even a good man is liable to open his relief

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valve too much. Not considering the economy involved in saving the steam relieved in the early stage of the cook, the heat that can be saved when relieving the pressure from 120 lb. down to 80 lb. corresponds to about 500,000 B.t.u. per ton of pulp, which is sufficient to raise the temperature of 500 gal. of water 125°F.

45. Any surface condenser of ample capacity will answer the purpose. A good type, one that has been used successfully, is shown in Fig. 9. Steam enters at *A* and leaves as water at *B*.

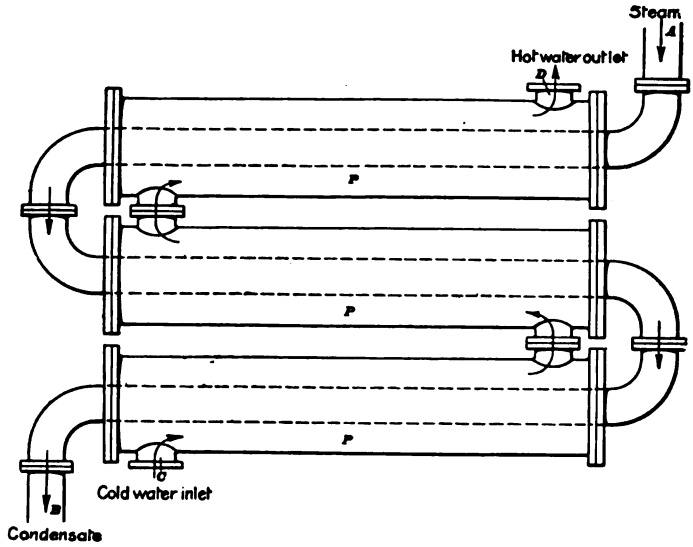

FIG. 9.

Cold water enters the jacket *P* at *C* and emerges hot at *D*. If preferred, a vertical box may be used instead of the water-jacket pipes *P*. The box is made any convenient height, but should be high enough to condense to water practically all the steam entering at *A* by the time it reaches *B*.

When the digester is blown, a large quantity of steam is released in a very short time, with a consequent and corresponding large loss of heat. A surface condenser able to take care of all this steam (condense it) must be of very large dimensions. A spray condenser is sometimes used for this purpose, but the condensate is likely to be contaminated with products derived

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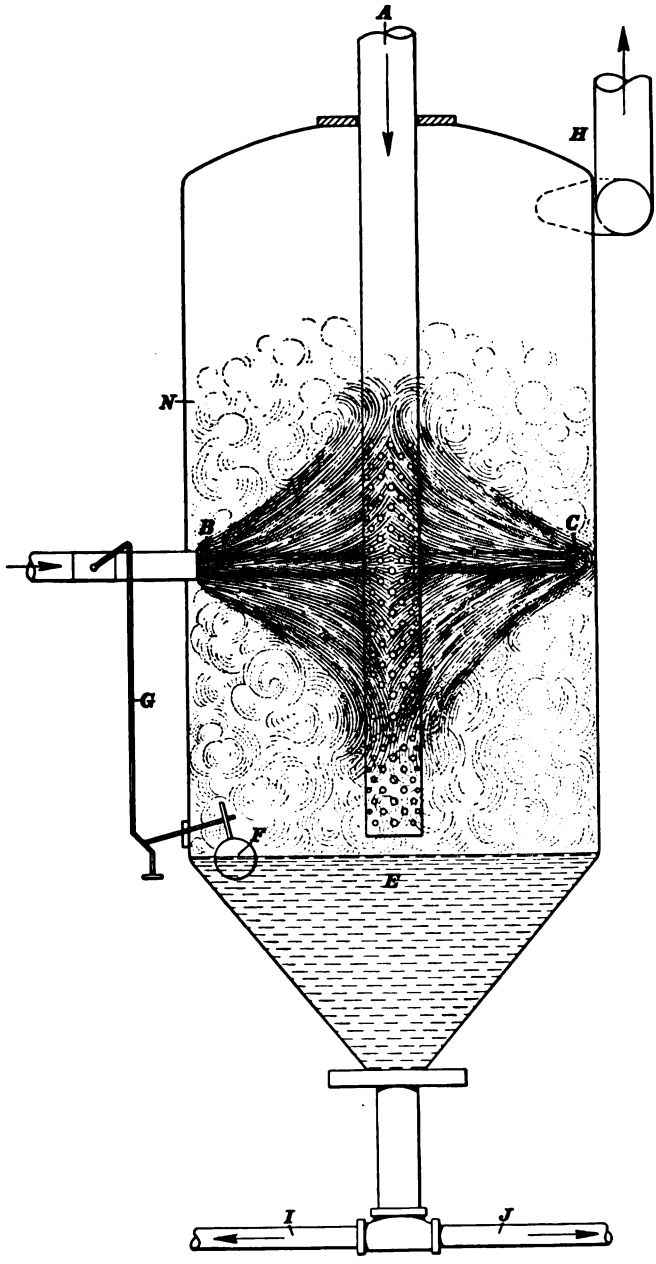

Fig. 10.

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from the cooking of the wood. A diagrammatic view of a spray condenser is shown in Fig. 10, which gives an idea of how it is arranged. The steam enters through the pipe *A*, which connects with the receiver, the lower end of this pipe being perforated, as indicated. As the steam discharges through the perforations, it meets the water spray from *B* and *C* and is condensed, falling to the bottom of the condenser, together with the excess water from the spray, as indicated at *E*. The level of *E* is controlled by the float *F*, the rising of which causes the link *G* to rise also and reduce the amount of water admitted to the condenser *N*. A vent pipe *H* keeps the pressure within the required limit. Pipe *I* connects to the sewer, and pipe *J* connects to the diffuser hot-water tank. The water is obtained boiling hot, and it is claimed that the bad odors of the water are not so strong that the water can not be used for washing purposes in the mill.

46. Testing Equipment.—A testing bench should be a part of the equipment of the digester room, so the cook can test the cooking liquor. A burette, some measuring flasks, and some pipettes are all the apparatus needed. A burette that will automatically adjust itself to zero (0) when filled, is to be preferred, because it eliminates the labor of adjusting or subtracting and lessens the chances for a mis-reading. The cook should also be furnished with a table showing how many inches of liquor are to be taken from the measuring tanks for the charge of active alkali that is wanted. This table makes it easy to change the charge of active alkali to correspond with changes in the wood and liquor. Such a table can be prepared by the chemist from a range of liquor analyses covering the possible range of the mill.

47. Indirect Heating of Cooking Liquor.—The advantages of indirect heating of the cooking liquor were appreciated very early in the development of the chemical pulp industry. This method of supplying heat for cooking does away with the diluting of the liquor, and the quantity of water that it is necessary to evaporate in order to reclaim the chemicals is less.

For several years, the problem of indirect cooking was not much heard of; recently, however, it has again become acute, and at the present time, there are at least three different systems on the market, for indirect heating. As the general features of these systems are all about the same, only one system will be described here.

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48. In Fig. 11 is shown a heater *A* installed on a digester *D*. The heater contains the tubes *C*, through which passes the live steam that does the heating. The liquor in contact with the outside of the tubes is heated by conduction, the heat of the steam passing through the walls of the tubes. The lower end of each tube is pressed or screwed into a substantial tube sheet, while the upper end is closed and free, thus permitting unlimited expansion. A false, perforated bottom *E* in the digester strains the liquor from the chips.

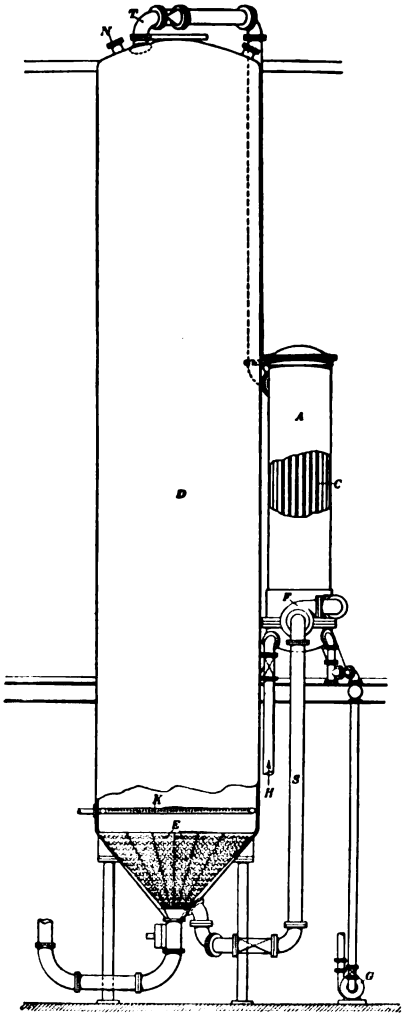

FIG. 11.

In operation, the digester is filled in the ordinary manner, the chips and the liquor being run in simultaneously. When half the liquor charge is run in, the circulating pump *F* is started up. It is claimed that this procedure effects a better packing of the chips. As soon as the digester is charged and the cover is on, the full pressure of steam is turned on through pipe *H*, and the condensate pump *G*, which discharges to the hot washing water storage, is started up. The cooking liquor flows from the bottom of the digester, through pipe *S*, the heater *C*, and passes on through pipe *T* to the top of the digester. The circulating pump *F* is able to handle the entire quantity of liquor in from 18 to 20 minutes; it requires a 5- to 7½-h.p. motor to operate it. The condensate pump *G*, which can be run with a 10-h.p. motor, will take care of five digesters.

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The liquor is heated very rapidly. At 25 lb. per sq. in. pressure, the cold gas and air are relieved; after that, no further relieving is necessary. The maximum temperature of the digester, 330°–335°F. (120–125 lb. per sq. in., gauge pressure), is reached within $1\frac{1}{4}$–$1\frac{1}{2}$ hours, with heating steam at 150 lb., gauge, without diluting the liquor, and without hurting the fiber through local overheating, which could hardly have been avoided when heating the digester that rapidly with direct steam. When the maximum cooking temperature is reached, the steam is shut off the heater, and the digester is then furnished with direct steam, as usual. The circulating pump is kept going for another 20-minute period, and the pump is then shut down. When the cook is ready to blow, the pressure is relieved in the ordinary manner, and the digester is then discharged.

Among the advantages claimed are: saving of coal, which is partly due to the smaller amount of liquor to be evaporated; saving of salt cake and lime; production of a stronger fiber; and a saving of wood, on account of the better circulation obtained.

The writer has experienced considerable trouble in discharging the digester, when operating this heating system; it was not possible to force the digester to empty its total contents, and some pulp would always be left at the bottom. To improve this condition, it was found necessary to discontinue the use of the heater and the circulating pump before the cooking temperature was reached, and to bring the pressure up to the last 15 lb. by means of direct live steam.

QUESTIONS

(1) How many heat units will be lost daily by radiation from a bare digester 8 ft. in diameter and 40 ft. (total) high, if the temperature inside is 300°F. and the temperature outside is 90°F.? Assume the bottom to be a cone, an element of which makes an angle of 45° with the horizontal, and that the top is flat. *Ans.* 15,515,000 B.t.u.

(2) In the last example, if the coal used contain 13,000 B.t.u. per pound and the boiler plant delivers to the digester 50% of the heat energy of the coal, (*a*) how many pounds of coal are wasted per 24 hours through radiation of heat? (*b*) what is the money loss, if coal is worth $7.00 per ton of 2000 pounds? *Ans* { (*a*) 2387 lb. (*b*) 8.$35.

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(3) Compare the advantages and disadvantages of rotary and stationary digesters.

(4) Why is good circulation necessary?

(5) What is the reason for passing the relief gases through a condenser?

FACTORS AFFECTING THE COOK

49. Effect of Sodium Sulphide and Sodium Hydrate.—Of the factors affecting the cook, the condition of the wood, the pressure of the steam and its corresponding temperature in the digester, the quantity of active alkali, the volume of total liquor, and the time the wood is exposed to the action of the liquor, are of the greatest importance. The relation between the sodium sulphide and the sodium hydrate, within certain limits, has but little influence on the quality of the fiber; but if the hydrate gets much in excess, 85% or more of the total active alkali, the fiber will be more like that obtained from a soda cook and the yield will be less, calculated on the basis of dry wood. On the other hand, an increase of sulphide to above 48%–50% will result in a slower action of the liquor. With all other conditions unchanged, an excessive quantity of sodium sulphide in proportion to the sodium hydrate, will result in an incomplete decomposition of the wood, and the fiber obtained will be raw and full of slivers. In order to complete the cooking within the appointed time, the charge of active alkali will have to be increased. The writer has observed this on several occasions when, on account of unsatisfactory lime, the causticity of the white liquor had to be lowered, which, in its turn, resulted in more sodium sulphide in relation to sodium hydrate. Whether an increase of pressure will help the conditions thus created by the excess sulphide, is doubtful; but, by making the cooking time longer, the result will be improved. According to various authorities, the best result from the cooking of sulphate pulp is obtained when 35%–40% of the active alkali of the white liquor consists of sodium sulphide.

50. Effect of Variation in Woods.—Variation in the condition of the woods will affect the cooking in several ways. If a mixture of different kinds of woods is used, a change in the proportions of the several varieties will influence the result of the cooking; one kind of wood will give more fiber than another; one kind will call for a harder treatment with alkali than another. DeCew

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gives the following figures for black spruce and hemlock; while they apply to mill results from soda mills, they are equally applicable to sulphate mills.

	Specific Gravity	Weight of cord (lb.)	Soda as Na_2CO_3	Soda %	Yield (lb.) in dry fiber per cord
Black spruce.....	0.41	2250	900	40.0	1000
Hemlock.....	0.42	2300	950	41.3	970

If these two kinds of wood are used in a mixture, a change in the composition of this mixture will naturally change the result of the cook, and it will call for an adjustment of the charge of total active alkali.

51. Effect of Moisture in Chips.—Of greater influence than variation in woods is the variation in the amount of moisture in the chips. With increased moisture, the chips will weigh more and will pack better in the digester. Thus the digester will hold more wood, dry weight, and the total active alkali will have to be increased, to maintain the same quality of pulp. The harder packing of the wood in the digester will lessen the dead space between the chips, and the larger quantity of water in the chips decreases the quantity of water that can be absorbed by the chips; thus a charge of moist chips will call for a smaller total volume of liquor than a charge of dry chips.

52. Effect of Temperature and Pressure.—It was stated in the Section on *Physics* that saturated steam always has a definite temperature corresponding to a definite pressure. It is convenient to know what pressure corresponds to a particular temperature; then, if the temperature at which the cooking is to be done is known, all that is necessary is to watch the steam gauge until the pressure gets to the point that corresponds to that temperature. These values are usually obtained from steam tables, but if such a table is not at hand, the pressure may be calculated by the following formula, which gives excellent results from 300° to 350°F.

Let t = temperature in degrees F.

P = absolute pressure (lb. per sq. in.)

$$P = 431.53 - 3.4144t + .007331t^2$$

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For example, suppose it is desired to know what pressure corresponds to a temperature of 320°F. Substituting 320 for t in the formula,

$$P = 431.53 - 3.4144 \times 320 + .007331 \times 320^2$$
$$= 89.6 \text{ lb. per sq. in.;}$$

the gauge pressure is evidently

$$p = P - 14.7 = 89.6 - 14.7 = 74.9, \text{ say } 75 \text{ lb. per sq. in.}$$

53. An increase in temperature, with other conditions in the digester unchanged, will have the tendency to make the yield of fiber smaller, the speed with which the liquor acts on the wood is increased, and, at the same time, the percentage of active alkali that is utilized within an equal period becomes larger. The following figures from a reliable source (Christiansen's "Natron-Zellstoff") show how the yield and the percentage consumption of the active alkali are affected by an increase from 320°F. to 350°F., with the same digester charge in both cases:

320°F.	Yield of fiber	= 48%
	Consumption of alkali used	= 54%
350°F.	Yield of fiber	= 44.6%
	Consumption of alkali used	= 76.3%

NOTE—The alkali utilized was here determined by titration and not, as in Klason's figures, by saturation with carbonic acid.

A low temperature is thus of great benefit to the yield. However, it is not possible to work at a temperature much lower than 320° and obtain a free fiber. Below this temperature, even a great excess of alkali will not give well cooked pulp. At 320°F., an excessive charge of alkali is called for, to obtain a favorable result within a reasonable time, and an increased yield is not sufficient excuse for using so much active alkali that in the cycle of the process such great losses will be created. The most favorable conditions as to the utilization of the active alkali furnished to the digester, and the quality and yield of the fiber obtained from the cook, occur at a temperature of 330°–335°F.

To maintain the highest possible capacity of the digester room, the maximum cooking temperature should be reached as early as possible. The steaming time for kraft pulp should not much exceed one-third the total cooking time, because the principal reactions that take place in the digester hardly start at a temperature lower than 300°F. (See Art. **41.**)

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54. Quantity of Active Alkali.—The quantity of active alkali used for charging the digester is, perhaps, the factor that affects most seriously the results obtained from the cooking. If increased, it will, under otherwise similar conditions, change most radically the qualities of the fiber and will decrease the yield. The following illustration is from Christiansen's "Natron-Zellstoff:" two parallel cooks were run; in one the quantity of active alkali was 23.6%, calculated on the dry weight of wood, while in the other, this was changed to 30.6 %; the change caused a decrease of yield from 43.5% (on the basis of bone-dry fiber to bone-dry wood) to 33.6%.

As previously mentioned, Art. **26,** Klason found that 20% of active alkali (NaOH) is the smallest quantity actually engaged by the organic acids that are derived from the complete destruction of all the non-cellulose constituents of the wood; and he pointed out that this quantity is insufficient in practice, and that under certain conditions, in order to obtain easy-bleaching pulp having satisfactory qualities, it will be necessary to use 30% to 33% of active alkali.

55. In the manufacture of kraft pulp, where a complete isolation of cellulose is not desired, it is possible to obtain an excellent product, and maintain a yield of about 50% fiber, with less than 20% alkali; but if the charge be made much smaller, it will then be necessary to adopt some means of mechanical treatment—kollergangs or refiners—in order to obtain a fiber that is suitable for the beaters. However, this mechanical treatment is very expensive; so much so, that it may offset the savings from the improved yield and the reduction in the losses of alkali. Nearly all manufacturers are trying to obtain a product that is ready for the beaters without applying any extra work, and, at the same time, to maintain the highest possible yield. The quantity of active alkali that is used varies, of course, from mill to mill, because of variations of other conditions. Satisfactory results are obtained when 20%–23% of active alkali is used, as compared with the dry weight of wood.

56. Total Liquor.—The volume of liquid used in the digester (the total liquor) should be kept as small as possible, to economize steam consumption. Too small a volume of liquid, however, must be avoided, as it will result in a lot of more or less burned or uncooked chips, which will be mixed with the perfectly digested

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fiber. This applies particularly to the stationary digester, whether directly or indirectly heated; but it is not so likely to occur in a rotary digester, where the tumbling assures a thorough mixing of chips and liquid. Again, with too small a total liquor charge, there will be a certain proportion of the chips that never come into contact with the liquor, at least, not in the early stage of the cook; but, at the same time, these chips will be exposed to the high temperature in the digester, which will cause a partial dry-distillation of the wood. Later on in the process, when the wood in the lower part of the digester is partly decomposed and the volume of the resulting liquor (increased by the condensed steam) is sufficient to cover these chips also, the decomposition of the wood is retarded by the dry distillation of the wood and the low content of the alkali, as well as by the decreased time for chemical action; as a consequence, these chips are not properly cooked when the time comes for blowing the digester.

57. Besides leading to inferior steam economy, too large a volume of total liquor, which a good cook (digester man) would never use, may also result in bad cooking, due to the fact that it is then very hard to relieve the pressure without pulling some liquor out of the digester through the relief line. At the beginning of the cook, when the relieving is so essential in order to obtain good circulation, the active alkali in the digester is not utilized, and a loss of liquor will mean a corresponding loss of alkali that was intended for digesting the chips. The final result may be the same as though insufficient alkali had been furnished to the cook, and the fiber will have a general rough-looking appearance, with hardly any chips properly cooked.

Too small a volume of total liquor will result in an excess of uncooked chips, which means a waste of perfectly good wood. Since the conditions that will call for a change in the amount of total liquor result, principally, from changes in the amount of moisture in the chips, a control of this condition of the wood will assist in deciding how much liquid is necessary for the charge. Besides the quantity of active alkali that is essential for the cooking, the operation of the digester is also affected by the amount of moisture in the chips; and a close study of the relation of these factors—the total liquor and the ratio of the total active alkali to the moisture in the chips—will assist in determining how to charge the digester.

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For a stationary digester, when cooking with direct steam, the necessary volume of the total liquor will vary between 45% and 50% of the digester volume, and it is rarely outside these figures. For a stationary digester, heated indirectly, where no condensation takes place, the total liquor charge must be made greater, or from 55%–60%; with a 60% charge, the liquor will usually show at the top of the digester. For a rotary digester, where it is necessary to cover only a little more than one-half the chips, 25%–30% of the digester volume is a safe charge of liquid.

One method for determining whether the digester is having sufficient circulation, is to place a short piece of plank on the manhole, and sit on it. An experienced man can tell by the surge of liquor against the digester whether it is getting proper circulation. Also, an experienced sulphate man can tell whether digesters are getting proper circulation, even before entering the plant, because there is a typical odor present when digesters are not getting proper circulation. The odor is due to the chips being burned on top of the charge, which, in its turn, may depend on bad circulation, but is usually caused by too little liquid in the digester. The total liquor should then be increased.

58. When to Blow.—The digester should be discharged as soon as the stage of digestion that is aimed for is reached, a point that can be learned only by experience with the wood and the digester, since a prolonged exposure of the fiber to the action of the liquor will cause a decrease in the yield and, at the same time, the quality of the pulp will suffer. This effect is not so marked in the manufacture of kraft pulp, where the charge of active alkali is hardly sufficient to cause any further action of the fiber; but, when cooking easy-bleaching pulp, where an excessive quantity of active alkali has to be used in order to obtain complete destruction of non-cellulose matter of wood, even a short delay in discharging the digester will cause great changes in the quality of the pulp and a considerable reduction in the yield.

59. The actual cooking time varies from mill to mill and with the size of the digesters; it is usually about 4 hours for kraft pulp, of which time, 1½ hours is used for bringing the digester up to the desired temperature. For easy-bleaching pulp, the cooking time is longer, or about 5 hours, because the time for steaming the digester is then made longer, in order to get the chips properly soaked with the liquor before the temperature is

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reached at which the most important reactions take place. If perfect circulation be maintained and the chips be uniform as to size and moisture content, the time for steaming the digester might be decreased without any harmful consequences, thus increasing the capacity of the digester room. The same result can be obtained by increasing the charge of active alkali, in which case, the cook must be discharged just as soon as it is ready; a short delay then will mean bad economy. It is safe to say that, in the long run, it is not profitable to overload a digester room by fast cooking with too strong a liquor; and that the installation of additional digesters, to obtain a larger production, will pay for itself.

QUESTIONS

(1) (*a*) What is the best percentage of Na_2S in the cooking liquor? (*b*) What is the effect of an excess of Na_2S? (*c*) of NaOH?

(2) State the best temperature for cooking sulphate pulp.

(3) What is the effect on the yield and quality of pulp of variations in the amount of active alkali used?

(4) Why should the volume of liquor be as low as possible?

THE DIFFUSER ROOM

60. Purpose of Diffuser Room.—In the diffuser room, or wash room, the pulp discharged from the digester is freed from the liquid, the black liquor, that results from the cooking. This black liquor, which contains all the chemicals used for charging the digester (but in different form and proportions) and also the organic substances dissolved from the wood, has to be reclaimed as carefully as possible. To this end, the stock is first washed with water until it is perfectly clean. Before the chemicals in the liquor can be made useful again, they must be freed from all water that keeps them in solution and from the organic substances that are associated or combined with them. To accomplish this regeneration of chemicals as economically as possible, it is the aim in the wash room to wash the stock clean with the least quantity of water, and, if possible, keep the concentration of the resulting liquor so high that the heat generated by burning the organic matters contained in it will be sufficient to evaporate all the water. That this result may be

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accomplished, not only will the wash room have to be very well arranged and most carefully worked, but the machinery all through the mill will also have to be modern and up-to-date.

61. Reclaiming of Chemicals.—In the early days of the soda-pulp industry, the chemicals from the pulp contained in the wash water were all wasted, and no regeneration whatever was attempted. The economy in saving as much as possible of the chemicals was soon recognized, and the first step in that direction was to drain all the liquor from the digester that would flow off by gravity. This liquor was then regenerated in a rather crude way, and was used over again, as much as 70% of the chemicals being reclaimed. The pulp was freed from the rest of the chemicals through washing in the digester and also in the beaters, but the weak liquor that resulted from these latter operations was wasted. The great economy that resulted from this recovery, and also the laws that prohibited the washing of the chemicals into rivers and streams, induced experiments having as their aim still more complete recovery. Various forms of apparatus have been designed for the purpose, most of them similar to the present diffuser in their general principles, but differently arranged, and at first, built only for a part of the digester charge.

The first **diffuser** was constructed by Dahl, the originator of the sulphate process. At present, there is hardly any arrangement other than diffusers used for washing wood pulp manufactured by the sulphate process; and it is the exception when machinery of any other construction is used, though the washing is performed in open vats, in some cases. For washing straw pulp, which is very slimy in its structure and, because of this, very hard to wash clean, Lespermont introduced as early as 1873 an arrangement of a series of pulp thickeners, working according to the counter-current system. It is claimed that by adopting this method of washing, the straw cellulose can be washed very clean, with small losses of alkali and with comparatively little water. A somewhat similar system has recently been installed in a Canadian pulp mill; it is said to give good satisfaction.

62. Washing in Open Vats.—If the stock be washed in open vats, it is necessary to have an arrangement situated outside the wash room, by which the steam that is developed when discharging the digester is separated from the pulp and liquor. This is generally done by means of a cyclone arrangement, one

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form of which is shown in Fig. 12. Here the pulp is shot in at the upper end of the cylindrical part *A* in a tangential direction, as indicated in view (*b*). The solid and liquid materials are thus given a speedy rotary movement, which keeps them from being pulled out by the steam that escapes through the top. At the lower end, the cylindrical part *A* joins the cone-shaped part *B* that connects to a pipe *C*, through which the digester charge empties into a washing vat. The steam and other gases pass the baffle *D* and sleeve *E* and emerge at the throat *F*. *G* is the pipe from the digester.

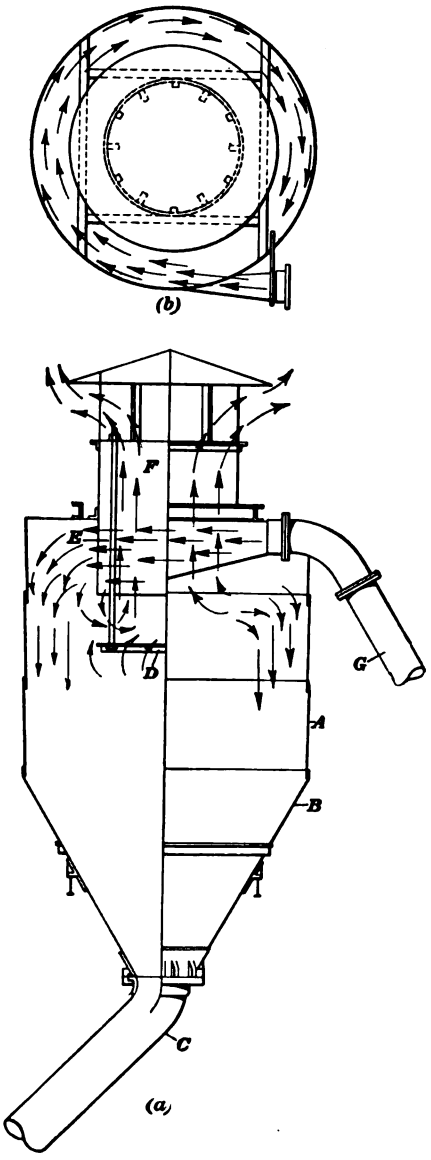

Fig. 12.

63. The wash tank is made of wrought iron, and is equipped with a false bottom, in most cases. Occasionally, there is a system of perforated pipes, placed right on the bottom and with the perforations turned downward, in order to save space in the tank. The purpose of the false bottom or perforated pipes is to obtain as large a draining area as is possible, and, at the same time, retain the fiber in the vat during the washing period. The perforated bottom is very similar to the false bottom used in the diffuser, and will be described later. A perforated pipe is

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placed in the top of the vat, through which the liquid used for washing is sprinkled over the stock. The bottom outlet of the vat is placed underneath the screen; it is so arranged that the liquor flowing from the tank can be directed either to the storage for black liquor for the recovery room or to a pump that discharges the liquor through the system of sprinklers on the top of the vats. A weak wash from one tank is used on a fresher charge in another. The vat is made large enough to hold one complete digester charge, and to allow a space for water of a depth of 12–18 inches. These open wash tanks, while still in use for soda pulp, have generally been replaced in sulphate mills by diffusers.

64. When the digester has emptied itself by blowing into the vat, the stock is leveled off and the drain valve is opened to the storage tanks. Before the stock is dry enough to permit cracks in the structure of the charge, through which water could escape to the bottom without properly serving its purpose for washing, weak liquor from another vat, where the strength of the liquor as determined by a hydrometer is considered too low to be sent to the recovery storage, is turned on through the top sprinkler pipes. This weak liquor wash is continued to a point where a further saving of the chemicals in the weak charge is considered to be uneconomical; the resulting liquor is then too weak to justify the cost of evaporation, and its cleansing effect is not satisfactory. The washing of the weak charge is then continued until it is considered clean, and the final resulting liquor is discharged into the sewer. The black liquor is collected in the recovery storage until the hydrometer shows density of about 5°Be. (hot), and the weak wash liquor is saved until its density is about 0°Be. (hot).

65. The washing of the charge, which up to now has been made with weak liquor, is continued with hot water, which is turned on through the sprinklers. The liquor that drains off through the bottom is admitted to the recovery storage until this tank tests weak (below 5°Be., hot), when it is turned on to another fresh charge.

When the stock has been washed, clean water is let in underneath the screen at the bottom, and the stock is flooded out through a manhole, placed on the side of the tank and opening into the stock chest.

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The open vat is a very slow working arrangement, and the volume of water used for washing is rather excessive. According to Sutermeister, *Soda Pulp Manufacture*, an actual time of 11–18 hours is needed to wash a layer of pulp that is 8–10 feet deep; of this time, 4–7 hours is required for collecting strong liquor and 5–6 hours for collecting weak liquor; the remainder of the total time is used for completing the wash. He gives the volume of strong liquor per ton of pulp as 1600–2100 gallons, and of the weak liquor as 1750–2220 gallons.

66. Description of Diffuser.—The diffuser shown in Fig. 13 is an enclosed tank *A* made from steel or wrought-iron plates, either riveted or welded. As compared with the open vat, the height of the diffuser is greater than the diameter, the ratio usually being about 2 to 1. The diffuser should be large enough to take care of an entire digester charge without getting so full that any considerable quantity of stock will blow out through the top, because of the velocity of the stock, when the digester is emptied. Good service in that respect is obtained from a diffuser that has about 10%–20% greater volume than the digester.

At the top of the diffuser is an opening with a special fitting *C*, which affords an entrance *B* for the stock from the digester and an outlet *G* for the escaping steam and, sometimes, liquor and pulp carried with it. On the same fitting, there is usually a connection for wash water, etc., as indicated at *D*, and, occasionally, for a safety valve *M*. Immediately underneath the pipe through which the pulp is blown into the diffuser, a baffle plate is securely fastened; this plate is cone shaped, with the vertex upwards, and serves to spread the pulp, so the bottom of the diffuser will not be exposed to the shock of the inrushing charge; it serves also to distribute wash water.

A false bottom consisting of screen *F* is placed as near as possible to the bottom of the diffuser. This false bottom must be of very strong construction, and its purpose is to make the draining area for the liquor as large as possible without letting any fiber through. The screen plate is usually $\frac{1}{16}$ inch thick, with $\frac{8}{32}$ inch perforations, spaced $\frac{7}{32}$ inch between centers. Underneath this top screen plate is a coarse wire screen, which keeps the top plate from contact with the heavy bottom plate and insures that the liquor will drain through all the holes of the top plate. The lower plate, which gives the false bottom its strength, is made from $\frac{1}{2}$-inch wrought iron, drilled with $\frac{1}{2}$-inch holes, spaced

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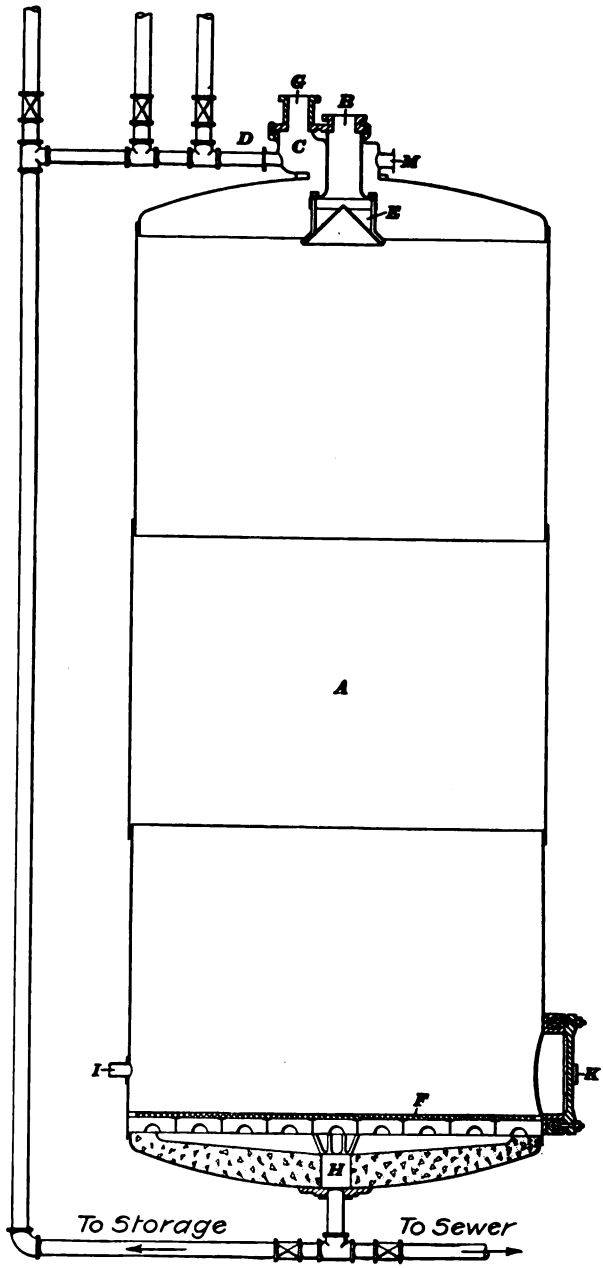

FIG. 13.

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1 inch between centers. All plates are made in sections, which can easily be taken out and replaced. The false bottom is supported on I beams, placed across the diffuser, and on an angle iron that is riveted to the shell and extends all around the wall.

The empty space under the false bottom is partly filled with concrete, which serves as a support for the beams and also decreases this space. If there is too much room under the screen, the space must be filled with liquor before the diffuser is blown into; otherwise, the false bottom will be subjected to a rather hard strain by the rapid flow of liquor through the screen at the start of the blowing; also, considerable fiber will find its way through the screen during this period of forced draining. When a concrete filling is put in, care must be taken to give a free passage for the liquor from every point of the bottom to the outlet *H* at the center. (Sometimes, the water from the last charge is left underneath the screen, to serve as a cushion for the bottom when the new charge is blown; this is bad practice, however, and will unnecessarily increase the volume of the water to be evaporated.)

The screen bottom is generally level, though sometimes sloped toward the front of the diffuser. A sloping bottom not only lessens the capacity of the diffuser but it also prevents the diffuser from washing uniformly, since the layer of pulp will be thicker at one side than at the other. The purpose sought, that of making the stock wash out more easily, is not accomplished either, because the water will run through the screen at the highest point and come up again at the front without bringing any pulp with it.

An opening *K* of ample size and fitted with a heavy cast-steel frame is placed in the side of the diffuser, level with the false bottom, to which is bolted a cover that can easily be removed. When the stock is ready washed, this cover is taken off, and the stock is dumped into the stock chest *T*, Fig. 14. To facilitate the operation of discharging the diffuser, a water inlet *I*, Fig. 13, is often placed opposite the dumping hole *K*, and about 12–18 inches above the screen. If the water entering at *I* be under good pressure, 40–50 lb. per sq. in., and the stream be distributed by some means over the entire bottom, practically all the stock can be washed out with but little trouble, and the time for emptying the diffuser can be made very short. At the center, in the

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bottom of the diffuser, is an outlet *H* for liquor and water, which may be conducted to storage tanks or to the sewer.

67. Battery of Diffusers.—The best and most common way of arranging a battery of diffusers is so to place them that their

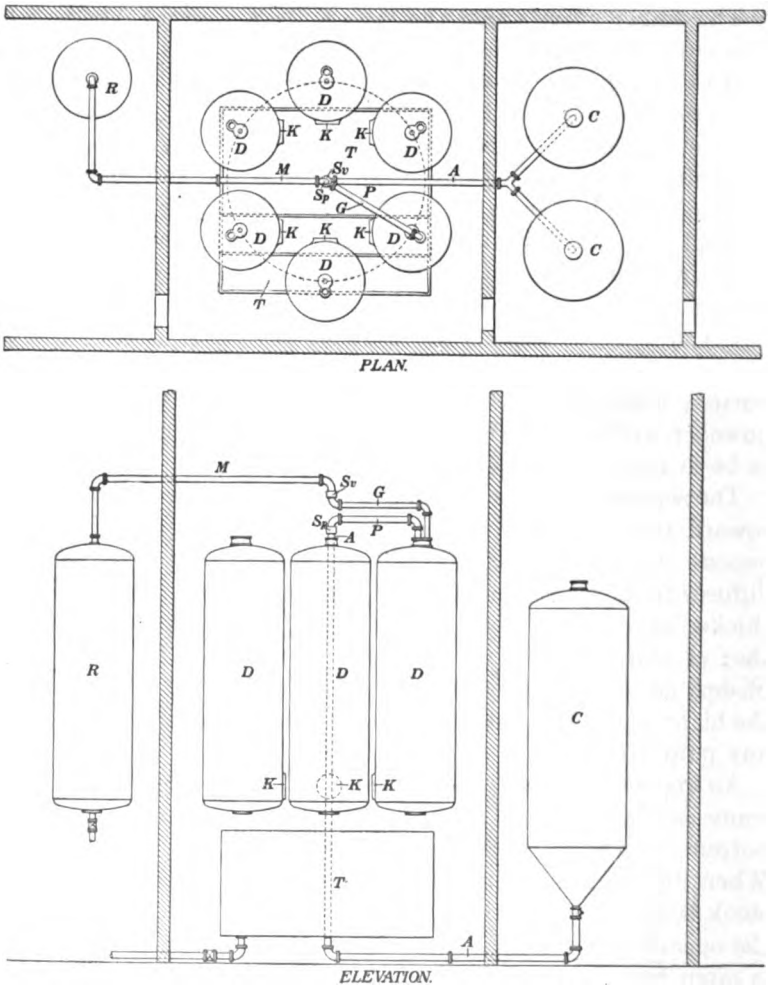

FIG. 14.

centers will lie on the circumference of a circle, as illustrated in Fig. 14. The discharge pipe *A* from the digesters *C* will have its outlet at the center of this circle, from which point, each

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diffuser D can be reached by means of a swing pipe P. Joints S_p are for pulp and S_v for vapor and gases.

The same effect may be obtained by placing the diffusers in a double row, as illustrated in Fig. 15, in which case, an extension L leads from each diffuser, to connect with the swinging arm P at the circumference of the circle. The former arrangement is to be preferred, because it is much easier to operate and is a neater looking arrangement. The latter is used only when the space

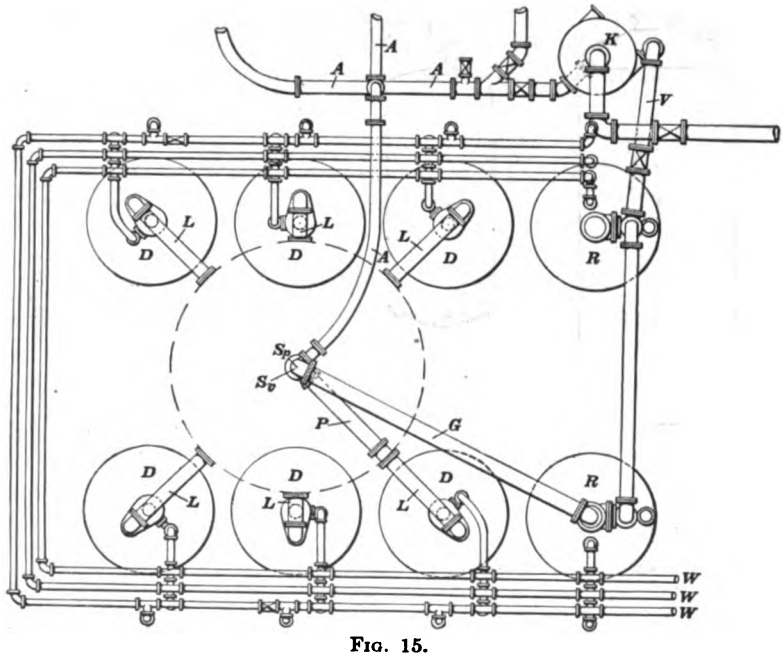

FIG. 15.

available for the diffuser room does not permit the circular arrangement.

While a diffuser is being filled, the steam and gases that are released are vented through pipe G, Figs. 14 and 15, to receiver R. Washed pulp is dumped through openings K to stock chest T, Fig. 14. Pipes for water, black liquor, and weak liquor are shown at W, Fig. 15. K is a dummy receiver that is used as a trap for pulp.

Fig. 16 shows how the connections are made when a diffuser is blown into. The charge in digester C is blown through the pipe line A–A–P into the diffuser D. The pressure in D is relieved

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through the pipe line that carries the steam and the particles of liquor and pulp, brought away with the steam, into the receiver *R*. From here, the steam (which is now practically freed from solid or liquid particles) escapes through the vent pipe *V*, discharging into the atmosphere, into a dummy receiver *K* (Fig. 15), or to a condenser. The first receiver is made exactly the same as a diffuser and is handled in the same way; the second receiver, the

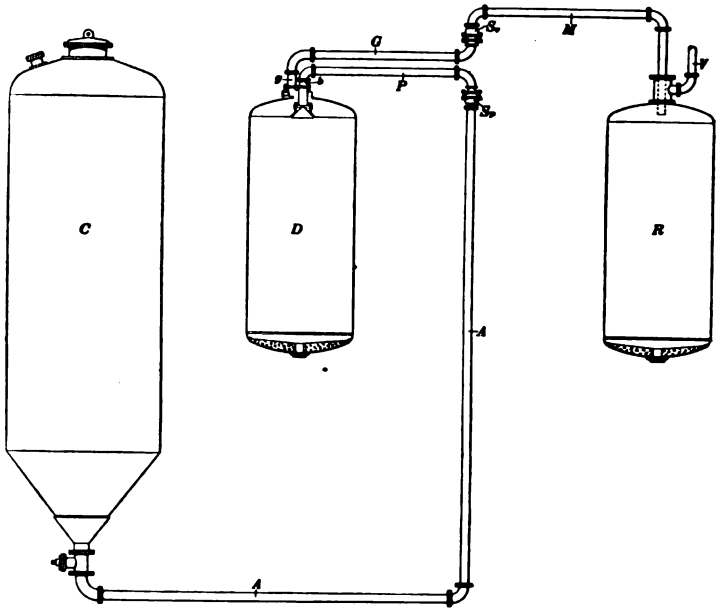

FIG. 16.

dummy, is made smaller, without any screen bottom, and is so connected that, when filled up, it can be discharged in the same manner as a digester.

The pipes *P* and *G* are bound together rigidly and can swing around the joints S_p and S_v, making connection with diffuser *D* at joints *b* and *g*. The diffusers constituting the battery are placed respectively on the circle described when the pipe system *P–G* swings around the joints S_p-S_v; or, when as in Fig. 15, extension pipes *L* lead to this circle.

68. When the diffusers are arranged in a circle, a double swinging pipe system, like *P–G*, Fig. 16, is common. This

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arrangement makes it possible to use any one of the diffusers in the battery as a receiver. The diffuser used as a receiver in one blow is then used to blow into the next time a digester is discharged, without being washed in between. In this way, the arrangement of having one or two diffusers installed for the purpose of serving as receivers alone, is avoided. On the other hand, it is always necessary to have two diffusers empty before a cook can be blown and, in addition, the second diffuser will be idle from the time it has been used as a receiver until it is blown into. It also entails more work in the diffuser room, since there will be twice as many connections to make each time; sometimes

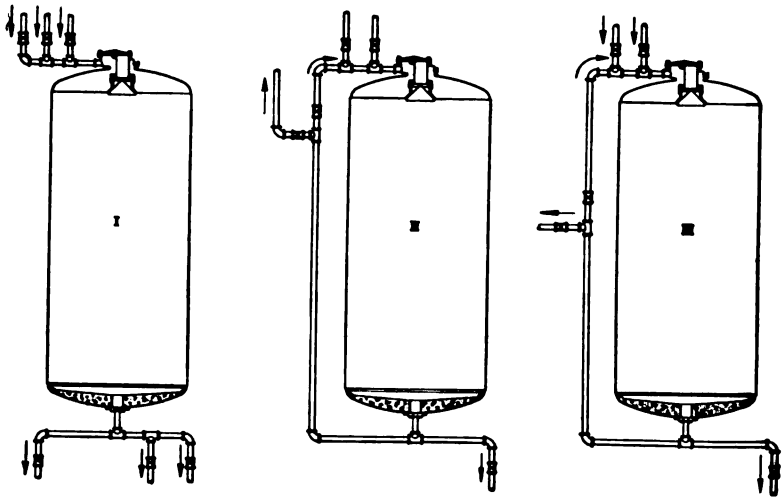

FIG. 17.

the swinging vent pipe is left connected with one diffuser until it is full, in the same manner as a receiver. In case separate receivers are used, there should always be two for each battery, if the diffuser room must work up to its capacity, in order that one can be washed and dumped while the other is filling up. If the diffuser is of ample size, one receiver should take care of at least ten cooks. If the receiver fills up too fast, it is advisable to reduce the blowing pressure on the digester.

The liquor and water piping for a diffuser are arranged in practice in various ways. The piping for the wash water always gives the same result, whatever arrangement is used. The wash water is discharged into the diffuser at the top; and the same

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arrangement is followed when high-pressure water is used for dumping the diffuser, unless a special inlet is provided, as shown at *I* in Fig. 13. It is not, however, immaterial how the liquor piping is arranged, and different arrangements appear to give quite different results. Fig. 17 shows three ways in which the liquor piping may be arranged.

69. In Case No. 1, the strong and weak liquor, as well as the drainage to the sewer, is taken out at the bottom of the diffuser. The strong liquor is piped to a special storage on a lower level than that of the diffuser bottom; the weak liquor is piped to another tank, from which it is pumped on a fresh charge. With the outlet for the strong liquor at the bottom, no precaution is taken to keep any liquid in the diffuser, and the stock is liable to drain clear at the bottom. This might cause cracks in the pulp layer and give the water a chance to find its way through the pulp without doing the proper washing; in practice, such is found to be the case. In many instances, it proved to be nearly impossible to wash the diffuser clean, the stock around the periphery of the diffuser staying unwashed, even when the liquor going out at the bottom showed that hardly any chemical was left. The volume of weak liquor obtained was also very large, compared with that of the strong liquor; in fact, it was too large to be used for washing purposes, although the change from strong to weak liquor was made at a test as low as 4°–5°Be. Curve I in Fig. 18 illustrates a typical result, obtained when washing a 3-ton diffuser, with the outlet free at the bottom, pulp directly cooked in a stationary digester.

70. The second arrangement in Fig. 17 shows the other extreme, with the outlets for the strong liquor at the top of the diffuser, or even higher. In this case, the diffuser will always be standing full of liquid; the stock will be considerably diluted, and the water that rushes in at the top is likely to get mixed with the liquor at the top of the diffuser. If this happens, the effect of the washing will be somewhat similar to cleaning out a vessel, filled with some liquid, by taking out a certain volume of the soiling liquid and replacing it with water, continuing this operation until the liquid in the vessel is practically pure water. This result could be reached much faster, using far less water, by emptying the vessel completely and adding water in small amounts at a time, the vessel being emptied after each operation.

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This latter illustration is an extreme case, of course, because the mixture of stock and liquid is rather thick and will not permit a perfect mixing; but it is true to some extent, as is shown by the rather slow drop of the test of the liquor at the end of the washing, when the pipe is thus arranged. This manner of piping the liquor is superior to the first arrangement; one advantage is that the operation valves are concentrated on one level, thus making it possible to discharge the strong diffuser-room liquor into tanks, from which it may be fed by gravity into the evaporators.

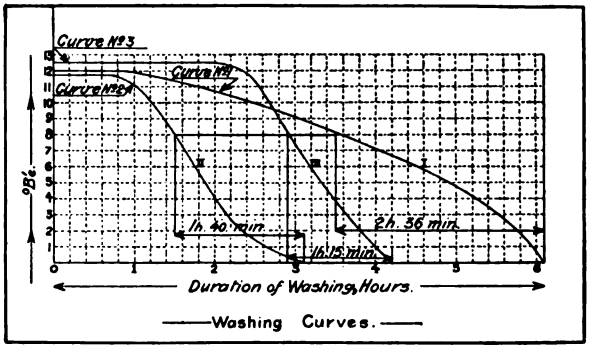

FIG. 18.

Curve II, Fig. 18, shows the result of washing by this arrangement in a 2.3-ton diffuser, pulp directly cooked in a rotary digester.

71. The ideal place for the drain pipe for the strong liquor is at such a height that the stock in the diffuser, when left to drain by itself, will be thick enough to prevent the liquor in the stock from mixing with the water or weak liquor that is run in from the top; at the same time, the pulp must neither pack so hard that it will offer too much resistance to the washing nor become dry enough to permit in its structure the formation of cracks and channels for the water. The height of the outlet from the bottom of the diffuser depends on the size of the diffuser as compared with its charge; but, as a rule, the best place is about the middle of the diffuser, as shown in III, Fig. 17.

This last arrangement of the drain pipe makes it possible to blow into the diffuser, with the drain valve open, without exposing the bottom to too much strain and without getting the stock packed too hard at the bottom of the diffuser. The flow of

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liquor from the diffuser during the blowing period is very rapid, and shortly after the diffuser is charged, all the liquor that will drain off by itself will be out. Curve III, Fig. 18, shows the result of washing a 2.6-ton diffuser, pulp directly cooked in a stationary digester, the piping being arranged as in III, Fig. 17. Note the relative time these three arrangements consume in delivering weak liquor below 8°Be.

72. Operation of Diffusers.—The usual manner of operating diffusers is to wash them in pairs; that is, when the liquor falls below a certain test, say 8°Be., instead of going to storage, it is passed from one diffuser to the top of the next one, and is there used as a primary wash as fast as it is obtained. In a battery of several diffusers, this is so managed that the first charge is blown in, say, No. 1 diffuser; the next charge is blown in No. 3 diffuser, proceeding in this manner until all the diffusers having odd numbers are filled. Then the following charge is emptied into No. 2 diffuser, the next into No. 4, and so on. No. 1 and No. 2 diffusers (also No. 3 and No. 4, etc.) are operated in pairs, the object being that No. 1 diffuser shall be washed down to a test that is set as a minimum for the storage tanks by the time No. 2 is blown into. This will also be the case with No. 2 when a new charge is blown into No. 1. As soon as No. 2 diffuser is charged and the self-draining liquor is run out, the weak liquor from No. 1 is turned on at the top of No. 2; No. 1 is then being washed with water, and this is continued until this diffuser is washed clean. By thus proceeding, the highest testing weak liquor will come in contact with the strong liquor in the fresh charge, and the dilution caused by the mixing of the two kinds of liquors, which will occur in spite of all precautions, will not be so high. As the test drops in No. 1 diffuser, the washing liquid used in No. 2 will gradually become weaker, until it is practically all water.

73. When the wash water is turned on, the diffuser becomes filled to the top, and the pressure due to the pump is then maintained until the washing is finished. This pressure creates a more rapid flow through the stock, which keeps the stock from floating up, but, at the same time, causes it to pack harder in the diffuser and create a greater resistance to the flow of the water. An excessive pressure of the wash water might thus unduly delay the washing. Since the call for water in the diffuser room varies considerably from time to time, it is very difficult to get a pump

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that will maintain the desired pressure under all conditions. To be able always to maintain the same pressure on the diffuser, it is advisable to conduct the excess water back to the tanks from which it is pumped, placing the return pipe on a level high enough to produce a natural head of water sufficient to create the desired pressure at the top of the diffuser. Favorable results of the washing, as regards time and the quantity of strong liquor, will be obtained with a water pressure of 18–20 lb. per sq. in. at the top of the diffuser, provided the outlet is placed midway of the height of the diffuser; with the overflow pipe higher up, the water pressure must be correspondingly increased.

74. As mentioned above, the resistance to the flow of water through the pulp increases toward the end of the washing. The weak liquor used for washing a fresh charge is thus obtained at a rate that is slower than the rate at which it will drain out of the next diffuser. Due to these conditions and also to the fact that No. 1 diffuser, for instance, might be weak ahead of time or not washed enough to be considered weak when No. 2 is blown into, the washing of the diffusers is often delayed considerably, when applying this system of washing in pairs. To increase the capacity of the diffuser room, the room is often equipped with special storage for weak liquor, from which weak liquor for washing purpose is taken whenever wanted. There will then be no waiting; but the gradual drop in test of the liquor in the different layers of the stock in the diffuser will not be so marked as is the case when the washing is conducted in pairs. When this latter arrangement is used, the volume of weak liquor necessary for each charge is pumped into the diffuser, which is then left to drain for a while, to give the weak liquor time to settle well down and keep it from mixing with the wash water.

75. The water used for washing should preferably be hot, and sufficient hot water may be obtained by installing a condenser for the relief from the digesters. The use of hot water will increase the speed with which the stock is washed and thus give a larger capacity to the diffuser room. The use of hot water for washing means that the evaporators will have less work to do, since the liquor coming from the diffuser room will be warmer. Insulation on the liquor storage tanks will also help to keep the liquor hot for the evaporators. By having a small storage for black liquor, the heat losses due to radiation through the

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tanks can be made smaller; but this will give a small margin on which to operate, and a large liquor storage is to be preferred.

In order to economize heat, it is the practice in many mills to use only a small volume of hot water for washing. The hot water is then used as a continuation of the weak-liquor wash, and is usually supplied from a special tank, which is placed high enough to allow the water to flow in by gravity. After the hot water (of which only a volume corresponding to 2–3 feet of the diffuser height is used) has settled down in the stock, cold water is supplied from a pump, and the washing is completed with this. The hot water acts like a plunger, with higher washing efficiency, and prevents any lowering of the temperature of the black liquor.

76. Dumping a Diffuser.—When the diffuser is washed clean, the manhole *K*, Figs. 13 and 14, at the bottom is opened up, high-pressure cold water is turned on at the top of the diffuser; and in case there is an inlet *I*, Fig. 13, at the bottom for water, this is also turned on. In this way, the principal part of the charge is dumped very quickly into the stock chest *T*, Fig. 14, which is situated underneath and between the diffusers. The stock that is left in the diffuser is washed out with a hose, using water under a pressure of about 50 lb. per sq. in. The entire operation of emptying the diffuser and putting on the door again should take less than 30 minutes.

The stock chest should be at least large enough to take care of one complete diffuser charge, with a consistency of stock in the chest not exceeding 2.5% bone-dry pulp. In case a fan pump is used to pump the stock, it is not advisable to figure on keeping the stock thicker than above mentioned, because trouble might then be experienced in getting the pump to throw. If a plunger pump be used, it will be possible to handle stock containing as much as 3.5% to 5% bone-dry pulp.

QUESTIONS

(1) Why is pulp washed?
(2) Why is hot water preferred for washing pulp?
(3) What is the first effluent called, and what does it contain?

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THE EVAPORATORS

77. Composition of Black Liquor.—The black liquor from the diffuser room contains practically all the chemicals that were used for the cooking and, in addition, the organic substances removed from the wood, see Art. **60,** all of which are kept in solution in a considerable quantity of water. The composition of the black liquor varies for different localities and from time to time in the same locality, but the average composition at 15°Be. and 60°F. is 900 grams of water and 225 grams of solid matter per liter of liquor; of the solids, about 50% is combustible. In order to regenerate the sodium compounds, it is necessary to remove the water and the organic matter; and it is the aim of the reclaiming process to generate sufficient heat to evaporate the water by burning the organic substances. The waste heat from the rotary furnace (described later) is, for this purpose, either utilized in a steam boiler and the steam thus generated used in multiple-effect evaporators or else the furnace gases are led into a direct evaporator, where they come into immediate contact with the liquor to be evaporated.

78. Direct Evaporation.—The early installations for direct evaporation were very imperfect, and only a small proportion of the heat contained in the gases from the smelting furnace could be utilized. The liquor was held in a pan and the gases were passed over the surface of the liquor. The evaporation surface thus obtained was very limited. In order to increase the surface touched by the gases without using pans of very large dimensions, Dahl constructed a rather complicated and expensive steam-boiler arrangement, feeding the boiler with black liquor. This arrangement and others more or less intricate, never found general acceptance, because the problem of obtaining sufficient evaporation surface was solved very simply by the use of disk evaporators.

DISK EVAPORATORS

79. Description of a Disk Evaporator.—If correctly installed, the disk evaporator is easy to operate and its up-keep cost is low; at the same time, it is very efficient and the cost of installation is low. Fig. 19 shows two views of the rotor of one type of disk evaporator; view (*b*) is a section on the line XX, and shows

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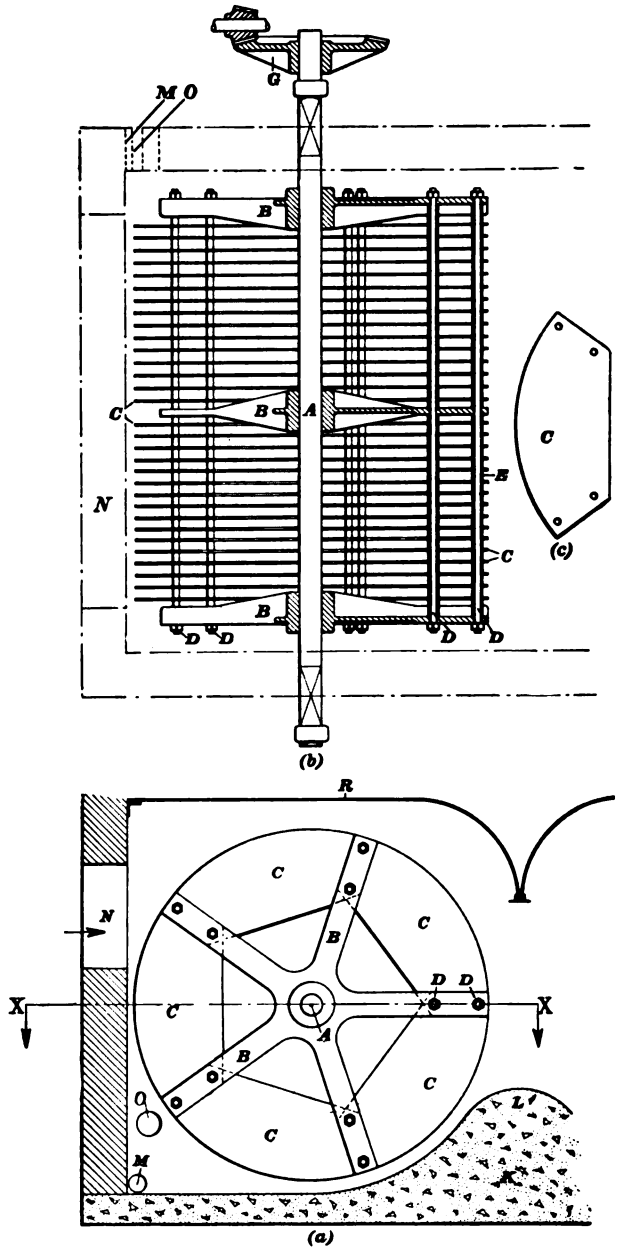

FIG. 19.

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the lower half. On a heavy steel shaft *A* are securely fastened 3 or 4 substantial cast-iron spiders *B* having 5 or 6 arms each. Between these spiders, the disk plates *C* are mounted and are supported by the rods *D*, which extend the entire length of the rotor. The disk plates are made from sheet iron that is from $\frac{3}{8}\frac{2}{2}$–$\frac{1}{8}$ inch thick; they are made in several sections, one of which is shown at (*c*), and each section takes in two or three sets of the rods *D*; the disk plates (rings) are separated from one another by spacers *E* that are made from pipe, and are 3 inches long. Since about one-sixth of the disk surface is at all times submerged in the liquor, at which time it does not come into contact with the hot gases, the surface touched by the gases (the effective evaporation surface), of 32 rings of a rotor, 8 ft. outside diameter, is about 1600 sq. ft. In some disk evaporators, every second section in the ring is omitted, in order to give the plates a spiral arrangement, which causes their surfaces to make an angle with the direction of the flue gases; this induces a slight sidewise motion in the gases, which has a tendency to make better contact between the gases and the liquor, and it also improves the reclaiming of the solid matters carried in the gases. This practice, however, practically halves the evaporation surface, and it necessitates an increased number of rotors.

80. The number of rotors for a disk-evaporator unit is determined by the capacity of the smelter; they should provide an evaporation area large enough to cool the gases from the smelter to the desired temperature. Good results will be obtained with two disk rotors, of about 3200 sq. ft. of active evaporation surface, for a smelter unit having a capacity of 18–22 tons of pulp. If the smelter capacity is adequate to handle a production of 25–30 tons of pulp, a third rotor must be installed, in order properly to utilize the heat. Referring to Fig. 19, the gases pass between the plates in a direction at right angles to the shaft *A*. As shown in view (*a*), the bottom *K* and the roof *R* of the evaporator are shaped to conform to the rotor.

81. The rotors may be installed in a concrete pan, which should preferably be lined with sheet iron up to the level of the liquor, to prevent leakage through cracks in the cement work, which are hard to avoid. The bottom *K* of this pan is made dish-shaped, so as to afford a clearance between it and the rotors of not more than 2 inches, in order to make the volume of the liquor carried

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in the machine as small as possible at any one time. The roof *R* is shaped similarly, in order to keep the gases in contact with the plates *C*. The raised part *L* of the bottom is made a little lower at its highest point than the liquor level, so the liquor may wash away any solid matter that falls on it. To permit all the liquor in the pan to drain through a single opening, in case it is necessary to entirely empty the pan, a canal that is level with the lowest part of the pan bottom and is about 8 inches wide is left on one side of the machine.

The rotors are driven by heavy gearing *G* on the outside of the pan; they should be run fast enough to keep the liquor from getting dry and burning on the disk plates. If the speed of the rotor be too high, it will cause splashing and foaming of the liquor in the pan, which will make the machine less efficient and may cause loss of chemicals; 10–12 r.p.m. is the standard speed for rotors. The rotor that is closest to the incinerator, where the liquor is heaviest and the gases are hottest, might be driven a little faster than the others, so the liquor will not burn on the disk plates, and to make them last longer.

82. The liquor is fed to the back of the disk evaporator, behind the last rotor; its density should be high enough to provide enough black ash to generate sufficient heat (when burned in the furnace) for any further evaporation that may be necessary. Liquor testing 17°–19°Be. at 60°F. will usually be satisfactory in this respect. This density is easily attained in multiple-effect evaporators, described later. Should the liquor get weaker than is required to give good black ash, additional heat must be supplied by means of a wood or coal fire. If wood be used, it can be fired in smelters direct; this cannot be done with coal, since the impurities in the coal ashes will cause an inferior grade of smelt, which will result, later, in a white liquor that gives trouble in settling. Consequently, it is necessary to burn the coal on a special grate, where the ashes will not enter the smelter. Should the test of the black liquor be persistently less than 16°Be., it will not pay to make all the necessary evaporation in the disks; better economy is then effected by bringing the liquor up to the desired density in a multiple-effect, indirect evaporator (see Art. **89**); too weak a liquor cannot be favorably handled in disk evaporators. The liquor then has to stay so long in the disk that the accumulated chemicals caught from the furnace gases makes the liquor gritty, and spoils it for making

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black ash. It is for this same reason that the liquor pan for the disk rotor is made dish-shaped and the volume of the liquor is kept as small as possible.

The liquor leaving the disk evaporator should test 26° – 32°Be. at the existing temperature, which corresponds to 32°–38°Be. at 60°F. The test to which it is necessary to bring the liquor will vary with the composition of the black liquor and with the length of the rotary furnace in which the evaporation is completed.

83. The outlet *O*, Fig. 19, for the black liquor is at the front end of the disk evaporator, either in the bottom or in the side. In either case, it should be so arranged that the level of the liquor cannot get lower than that at which the disk plate inserted in the liquor will be totally submerged. To carry a higher level of liquor in the disk evaporator is not advisable, since it will decrease the active area of the disks and will also make the quantity of liquor greater than necessary. In the bottom of the disk pan is another outlet *M*, which makes it possible to empty the machine completely. Hot gases from the burning black ash in the rotary or smelting furnace enter the evaporator through the opening *N*.

84. If the disk evaporator is placed high enough to permit the liquor to flow into the rotary furnace by gravity, it may not be necessary to screen the liquor; but if a pump is used to transfer the liquor from the evaporator to the furnace, it is advisable to have a screen box between the evaporator and the pump, for the purpose of catching the larger solids that are formed in the evaporator. A screen plate with ¾-inch perforations will serve nicely for this.

Whenever possible, the liquor should flow by gravity to the rotary from the disk evaporator. This saves the power required to drive the pump and the cost of its up keep.

85. When a body of air or gas is heated, it expands; its specific weight (density) decreases; the result is that the body of air (or gas) rises in the heavier air (or gas) surrounding it, just as a piece of light wood rises in water; the colder air (or gas) then flows in to take the place vacated by the lighter air (or gas); the current of cold air (or gas) thus created is called a **draft.** The phenomenon just described is the cause of winds, chimney drafts, etc. When the draft is produced solely by the action of

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heat, as in the above case, the draft is called a **natural draft.** If, however, the air is moved by mechanical means, as by an exhaust fan or a blowing fan, the draft that is created is called a **mechanical draft.**

When natural draft is employed to move the gases through the evaporator, the utilization of heat generated by burning the black ash is limited to raising the gases to a temperature sufficient to create a draft necessary to carry them away; and this temperature can be made lower by increasing the height of the stack. But, even with an exceedingly high stack, or if a fan be used to create the draft, it is not advisable to let the temperature of the gases escaping go below 200°–210°F., as there is then danger that the steam will condense to water on the last rotor instead of the water evaporating. If it be found necessary to let the gases leave the disk evaporator at a temperature higher than 250°–275°F., it will probably be economical to use mechanical draft and increase the evaporation surface of the disk evaporator, so the temperature of the escaping gases will be about 210°F.

86. Another Type of Disk Evaporator.—In Fig. 23 is shown a disk evaporator *A* of a different type from that just described. Here the disk plates are placed at right angles to the direction of the flow of gases, the plates being so arranged that the gases are forced to take a tortuous zig-zag course through the machine. This produces more thorough agitation of the gases, and the contact between the gases and the liquid is more intimate; also, the solid particles that are carried by the gases (which are heavier and do not so easily change their direction as the gases) are more likely to get caught by the liquor on the disks. The great resistance offered by this evaporator to the movement of the gases necessitates the use of mechanical draft. It is claimed that the greater efficiency that is obtained by this arrangement is offset by the cost of operating the fan to produce the draft.

87. Use of Steam Boiler with High-Pressure Evaporator.—In the Scandanavian countries, the most modern sulphate mills have adopted a steam boiler to take care of the waste heat from the rotary furnace. The steam generated in the boiler is used in a high pressure evaporator for concentrating the liquor, and the vapors from the last effect of the evaporator are condensed in the cylinders of a drying machine. In this way, it is possible not only to evaporate all the water in the liquor but also to dry

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all the finished product without furnishing any fuel other than that found in the black liquor. Any type of steam boiler may be used for this purpose; but it must be so installed as to be easily cleaned, since a dust of chemicals accumulates rapidly and must be blown off the tubes frequently. The rating of the boiler is rather low and the first cost is heavy, but the economy resulting from the operation of this installation justifies the expense. American operators seem to favor the use of the heat in the gases from the rotary for evaporating liquor by passing them through a disk evaporator, which also reclaims as much as possible of the sublimed chemicals in the gases. If any heat is left, the gases may then be passed through an **economizer,** which is a device for heating water by means of hot gases before they enter the stack.

88. It is only in the most up-to-date mills, where every precaution has been taken to minimize the volume of black liquor obtained from the diffuser room, that it is possible to perform all the necessary evaporation with the heat that is obtained through burning the organic substances in the black liquor. Before passing the liquor to the disk evaporators, the excess water is usually removed in a multiple-effect, indirect evaporator. Steam is furnished in the first effect as a source of heat, but in the other effects, the vapors from a previous effect serve the same purpose; the vapors from the last effect are condensed, by some means, outside the machine. In order to utilize as much as possible of the heat supplied to the apparatus, and to maintain it at a large capacity, two or more effects of the apparatus work under vacuum, that is, the pressure is below that of the atmosphere.

89. Principle Governing Multiple-Effect Evaporators.—To analyze intelligently the work of this type of evaporator, certain physical laws applying to evaporation must be taken into account. The quantity of heat that is conducted from steam through a metal sheet to a boiling liquid is: (1) directly proportional to the area of the sheet; (2) directly proportional to the time; (3) directly proportional to the difference in temperature between the two sides of the sheet; (4) inversely proportional to the thickness of the sheet. (See Transmission of Heat in Section on *Physics*.) The only other factor that can affect the conduction of heat is the material of which the sheet is made. Iron tubes are the only material used, but if steel should be employed,

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the difference in heat conductivity between iron and steel is too small to be considered here. Variation in the thickness of a tube, within certain small limits, has also but slight influence on the capacity of the machine.

As pointed out in *Physics*, the temperature of the vapors over a boiling liquid that is contained in a closed vessel is always the same for the same liquid and the same pressure; also, if the temperature (or pressure) is increased, the pressure (or temperature) is likewise increased. In other words, there is a definite temperature for every pressure, and a definite pressure for every temperature, for any particular liquid. The boiling point of black liquor is higher than that of pure water, and the difference increases as the density of the black liquor increases. Whatever the liquid, the temperature of boiling decreases as the pressure decreases.

When steam (or other vapor) condenses, heat is given up (latent heat of vaporization) and becomes available as heat energy; it may be called the *heat of condensation.* In the case of an evaporator, the heat of condensation is transmitted through the walls of the tube containing the condensate (condensed steam) and is absorbed by the liquor that surrounds it. The temperature of the liquor is raised, and the object is to heat this liquor sufficiently to start it to boiling. Suppose a single-effect evaporator were used for this purpose, and suppose further that the efficiency of the machine were 100%; then *all* the heat energy by the condensation of the steam would be absorbed by the liquor. A part of this heat raises the liquor to the temperature of boiling at the existing pressure (if the liquor is not already at that temperature), and the remainder supplies the heat necessary to convert the liquid into a vapor (the latent heat of vaporization). Ordinarily, the vapor escapes from the machine, and all the heat contained in it is thus lost. To save the heat in the vapor that escapes from this one effect, it is condensed in another effect, where it takes the place of live steam; and this may be repeated again and again, according to the number of effects.

90. A general layout, in elevation, of a **quadruple-effect, vertical-tube evaporator** is given in Fig. 20, and a vertical and a horizontal section of one of the effects or units is given in Fig. 21; the same reference letters are used for the corresponding parts in both illustrations. Each effect (unit) consists of a bottom chamber *A*, a tubular heating-unit chamber *B*, and a vapor-

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separation chamber C. Here the heating unit is a nest of tubes D (2 inches external diameter) for the up-flowing liquor, and a certain number of larger tubes D' (4 inches external diameter), which act as down-flowing or circulating tubes. All these tubes are expanded into the upper and lower flat tube sheets E, and steam or other vapor is confined to the space around the tubes. The foam is kept just above the top tube sheet E. Since there is a large area in a small tube in proportion to the volume of liquor it contains, the liquor in the small tubes boils first, and the vapor rises and escapes into the vapor chamber C, where it partly condenses, the condensate passing down the larger tubes D'.

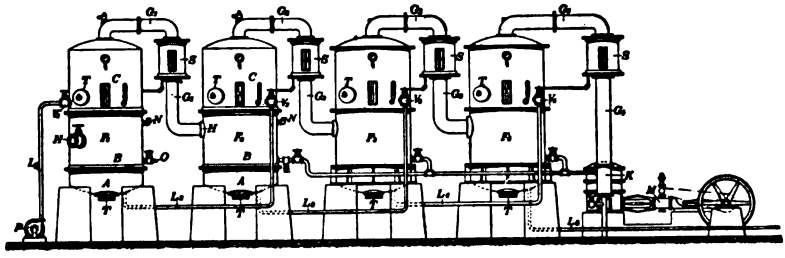

FIG. 20.

For foaming liquors, as in pulp mills, a high vapor space is essential, to avoid entrainment of the liquor particles, which would be carried away in the steam; any such liquor leaving the space C in the steam is caught in the save-all S, Fig. 20, and is returned to the evaporator.

The steam from the first effect F_1 passes through vapor pipe G_1 to the heating unit B of the second effect F_2, entering at H; the steam generated in F_2 goes through G_2 to the tube chamber of the third effect F_3; etc. Live steam is fed into the first heating unit F_1 at H, while the steam from the last effect is condensed in some form of condenser K. A vacuum pump M is usually required to remove gases that will not condense and which are mixed with the vapor (steam). These gases may also be removed from the steam space by connecting the air-relief cock N, Fig. 21, to the vacuum pump. The condensation from heating steam that occurs in the chamber B passes out through O, and is conducted to the drain or to the boiler, provided there is no vacuum in B; otherwise, this tailwater goes to the vacuum pump, M, Fig. 20. Unless fed by gravity from storage, a black-liquor feed pump P

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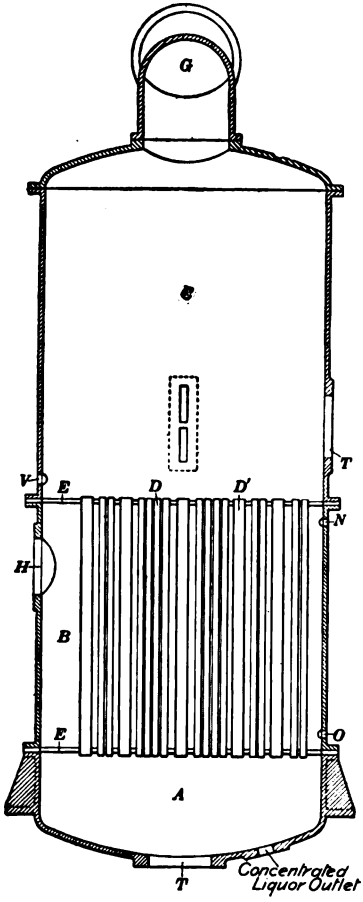

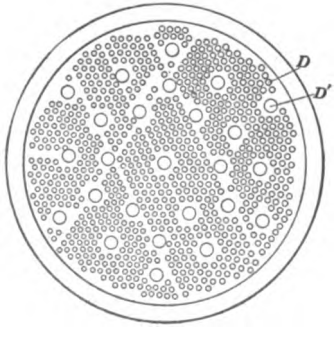

FIG. 21.

supplies weak liquor to the first effect F_1 through pipe L_1 and valve V_1. Pipes L_2, L_3, and L_4 connect the other effects, and pipe L_5 takes the concentrated liquor to the storage tank for the disk evaporator.

91. Operation of a Quadruple-Effect Evaporator.—It is customary in pulp mills to supply a quadruple-effect evaporator with steam at, say, 40 lb. per sq. in. for the first effect and to have a vacuum of 26 inches for the last effect. The temperature of steam at 40 lb., gauge, is 287°F. and at 26 in. vacuum, it is 127°F.; the temperature range is thus 287 − 127 = 160°F. To secure the best results, this range of temperature should be divided as equally as possible in each effect; that is, the difference between the temperature outside the tubes in chamber *B* and the temperature inside the tubes should be, in this case, 160 ÷ 4 = 40°F. Thus, the temperature outside the tubes in the first effect F_1 is 287°F. and that inside the tubes should be 287 − 40 = 247°F.; these temperatures correspond to gauge pressures of 40 lb. and 14 lb., respectively. In the second effect, F_2, the temperature outside the tubes will be the same as that inside the tubes of the first effect, or 247°F., and that inside the tubes should be 247 − 40 = 207°, which corresponds to a

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vacuum of 3 in. In the third effect, F_3 the temperature outside the tubes will be the same as that inside the tubes of the second effect, or 207°F., and that inside the tubes should be 207 − 40 = 167°F., which corresponds to a vacuum of about 18½ in. In the fourth (last) effect F_4, the temperature outside the tubes is the same as that inside the tubes of the third effect, or 167°F., and that inside the tubes is 167 − 40 = 127°F., which corresponds to a vacuum of 26 in.

Of course, were the initial pressure of the steam supplied to the first effect higher or lower than 40 lb. per sq. in. or the vacuum lower or higher than 26 in., the above working conditions would be varied accordingly. The object is to maintain a regular temperature difference throughout each effect, in order to obtain the proper amount of evaporation from each effect, as well as proper fuel economy.

Under the conditions just mentioned, the liquor moves through a quadruple-effect evaporator as follows: The weak liquor is delivered to the first effect F_1 through inlet valve V_1, usually by a centrifugal pump. The progressive movement of the liquor from one effect to the next is effected by the difference in the boiling pressure in each machine, which makes it unnecessary to pump from one to the next. Thus, as mentioned above, the liquor inside the tubes of the first effect boils at a pressure of about 14 lb. gauge = about 14 + 15 = 29 lb. abs., and the liquor in the second effect boils at about 3 in. vacuum = about 13.5 lb. abs. Consequently, this difference in pressure, 29 − 13.5 = 15.5 lb. transmits the liquor from the first to the second effect, and it is transmitted from the second to the third and from the third to the fourth effects in a similar manner. The liquor becomes more concentrated as it leaves each effect; and when it leaves the last effect in its finally concentrated form, it is delivered to a storage tank, from which it is fed to the disk evaporators or to the rotary incinerators.

The water condensed from steam in the first effect is conducted to the boiler supply or diffuser hot-water tank; from the second effect, directly or through the vacuum pump, to the drain; from third and fourth effects, also to the drain. The first condensate is pure water; the others are contaminated by liquids and gases derived from the wood.

At the bottom and side of each effect is a manhole T, to afford access to the tube sheet E, for cleaning and replacing tubes.

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However, the rapid circulation of liquor makes cleaning hardly necessary, beyond an occasional boiling out with water, except under conditions which permit a hard scale to form (see Art. **94**).

92. In Fig. 22, is shown a partial vertical section and partial elevation of an evaporator having horizontal tubes. In this

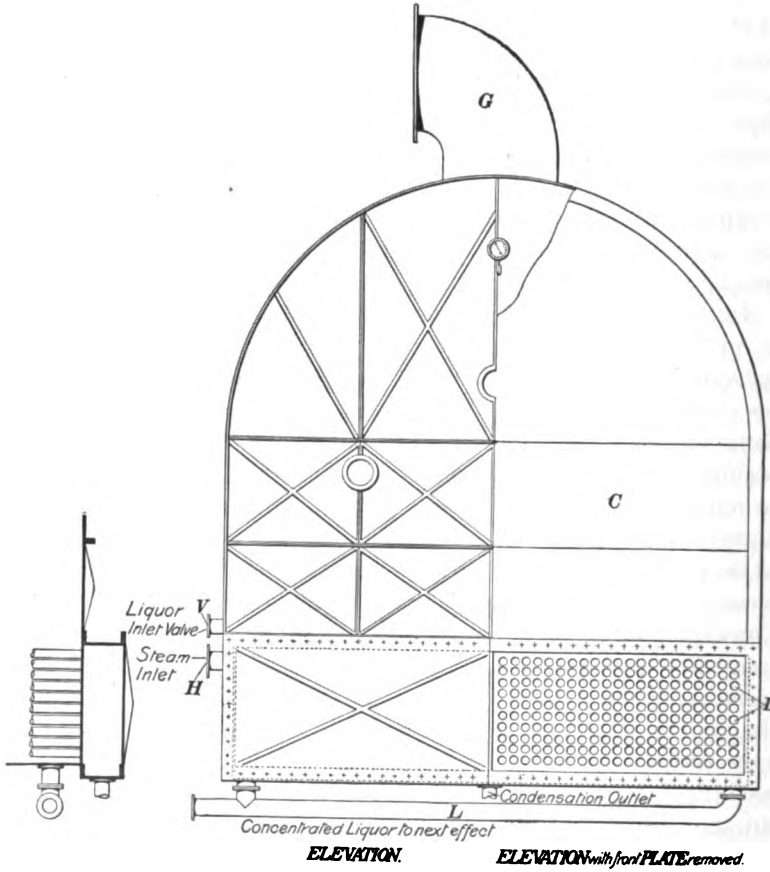

FIG. 22.

apparatus, the steam is inside and the liquor is outside the tubes. The courses of the vapors and the liquor are essentially the same as for the vertical type shown in Figs. 20 and 21, and the letters are the same for corresponding parts in all three figures.

93. Above the liquor side, Fig. 20, of the first effect, is a vapor space *C* that is directly connected to the steam space of the second

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effect; and if the connections between the two parts are sufficiently large, practically the same conditions as to temperature and pressure will prevail in both places. Hence, the condensation of the vapors in the steam chamber of the second effect takes place at nearly the same temperature as does the evaporation of the liquor in the first effect, and the condensed water that leaves the second effect will be of the same temperature as the boiling liquor in the second effect. Provided there is no loss of heat in the vapors on their way between the two parts of the space, all the heat that is carried away in the vapors from the first effect will be absorbed by the liquor in the second effect. Since the heat given up by condensation is the principal part (proportion) of the heat of the steam furnished in the first effect, the result is that the quantity of water evaporated in a double-effect evaporator is nearly twice as great as that obtained from the same quantity of steam in a single-effect evaporator.

Applying the same reasoning to a triple-effect evaporator, the work done by the steam ought to be about 3 times that done in a single-effect evaporator, and the work done by the steam in a quadruple-effect evaporator ought to be nearly 4 times that done in a single-effect evaporator; by *work* is here meant the amount of water evaporated. Results obtained from multiple-effect evaporators confirm this reasoning. According to Kirchner in "Das Papier," 1 lb. of steam evaporated 0.95 lb. of water in a single-effect evaporator, and it evaporated 1.90 lb. and 2.85 lb. in double- and triple-effect machines, respectively.

94. High-Pressure Evaporators.—The capacity of an evaporator depends upon the temperature difference between the several effects, and the greater this difference the greater is the capacity of the machine. When the pressure in the tubes of the last effect is above that of the atmosphere, it is necessary to start with an initial temperature of the steam corresponding to a high pressure, in order that the machine may have great capacity and that its dimensions may not be too large. While this necessitates very strong construction, which increases the first cost of the installation considerably, high-pressure evaporators have, nevertheless, been favored in some mills, because it is then easy to take care of the heat contained in the vapors from the last effect. Delivered under a pressure of from 15–20 lb. per sq. in., these vapors are used on the dryers of a pulp or paper machine. Several mills equipped with this type of evaporator are able to dry

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their total output of pulp up to 100% air-dry without furnishing any extra steam. High-pressure evaporation makes unnecessary the cost of operating the machinery required to remove the condensate and to maintain the vacuum in the low-pressure evaporator. Considerable trouble, however, is experienced in operating this type of evaporator on black liquor from the sulphate process. On account of the high temperature, especially in the first effect, a precipitation of the insoluble silicates of aluminum and calcium, which come from the smelter, takes place on the tubes. The scale that is thus formed is very hard to remove; in some instances, it has proved necessary to install a spare first effect, to give time for cleaning.

95. Advantages of Low-Pressure Evaporator.—As previously stated, the main source of heat for indirect evaporation is the latent heat given up when the steam condenses. This heat is nearly the same per pound of steam at whatever temperature (pressure) the steam condenses. By maintaining as high a vacuum as possible in the last effect, a big drop of temperature can be obtained within the machine and still make it possible to start in the first effect with a temperature of steam that corresponds to a rather low pressure (Art. **91**). Thus the initial steam pressure for the evaporator system can be considerably less than ordinary boiler pressure. By employing a low-pressure vacuum evaporator, and reducing the steam from boiler pressure to the desired initial evaporator pressure in a steam-driven power generator (engine or turbine), it is thus possible to generate a considerable quantity of mechanical energy and still have heat for the evaporator. The power generator will then be operated very cheaply, since it takes only a little more fuel to raise the steam to ordinary boiler pressure, once it is steam, and there is use for low-pressure exhaust steam in the evaporator.

Scale forming on the tubes of a low-pressure evaporator seldom occurs, because the temperature of the liquor is never high enough to precipitate the insoluble silicates. The first cost of a low-pressure system is less than that of a high-pressure system, as the construction can be made much lighter and, therefore, cheaper; but the cost of, and the expense of, operating the auxiliary pumps and condensers is considerable.

Considerable mechanical work must be performed in maintaining the vacuum in, and removing the condensate from, the effects that work under vacuum. The weakest feature of the vacuum

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evaporator is the loss of heat in the vapors escaping from the last effect. Due to the low quality and low pressure of this steam, it is very difficult to utilize the heat it contains; in ordinary practice, this steam is allowed to go to waste in a spray condenser or in a vacuum pump. In the end, a low-pressure system is more expensive than a high-pressure one.

In spite of the greater expense involved in a low-pressure evaporator, this type is, as yet, the one preferred in the sulphate-pulp industry. In order to maintain the greatest possible capacity and secure the greatest economy in the operation of the system, the highest obtainable vacuum must be maintained on the liquor side of the last effect.

96. Pumps Required.—Two types of pumps are used to create the vacuum in the evaporator, and both are about equally satisfactory. In one type, the *wet vacuum pump*, the water that is needed to condense the vapors from the last effect and to cool the condensate to a temperature at which the best possible vacuum is obtained, is taken in at the pump itself. In the other type, the *dry vacuum pump*, only the non-condensable gases are handled; the pump is supplementary to a condenser, usually a spray condenser, where the steam is condensed. The water is then removed from the condenser by a special pump, unless the condenser be, preferably, of the barometric type and is placed high enough (34 feet or more) to permit the water to run out of the condenser by gravity.

97. Operation of Indirect Evaporators.—Indirect evaporators are usually operated according to the **direct-flow system,** that is, the vapors and the liquor follow the same path through the machine. This method of operation makes it possible to let the liquor flow by itself from effect to effect, and it is necessary only to pump the liquor into the first effect and out of the last effect; the result of this is that the heaviest liquor, that having the highest boiling point, is heated by vapor of the lowest temperature. However, the direct flow is much more convenient in operating the machine, and it is, for that reason, the way of running most favored.

The **counterflow system,** where the weakest liquor is charged on the last effect and is brought by pumps from one effect to another opposite to the flow of the vapors, has never been successfully operated on black liquor, because of the foaming that

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occurs when the weak liquor is let in under the high vacuum of the last effect.

A more feasible method would be the **mixed-flow system** in which the weak liquor would be charged on the second effect; it would then flow through the following effects, and the rather heavy liquor in the last effect would be pumped into the steam-heated first effect, where the evaporation would be completed to the desired consistency. In mills where all the evaporation is done in indirect evaporators before discharging to the rotary furnace, the liquor will have a very high consistency in the last effect at the temperature prevailing in it, and it will offer a heavy resistance to the escaping vapors. This condition will certainly be improved by having the final evaporation occur in the first effect, since the higher temperature therein will make the liquor thinner, although its concentration will be the same as before.

98. Types of Evaporators.—The different makes of evaporators may all be arranged into two principal types: horizontal-tube evaporators, and vertical-tube evaporators.

In the **horizontal-tube evaporator,** the liquor may be outside and the steam inside the tubes, or the liquor may be inside and the steam outside the tubes. In the former, the length of the tubes has nothing to do with the height of the liquor layer; this makes it possible to get a comparatively large evaporation area and still keep the level of the liquor layer low. This is an advantage, since a shallow liquor layer offers less resistance to the escaping steam bubbles. It is to be noted that the horizontal tubes are harder to clean from scale or deposits of pulp that may occur on the tubes.

The **vertical-tube evaporator** usually holds a greater depth of liquor than the horizontal-tube type; consequently, the steam bubbles formed at the lower end of the tubes meet greater resistance when escaping. The liquor is here admitted to the inside of the tubes, and any deposits on the surface of the tubes are more easily removed. It is usually easier to re-tube a horizontal machine than a vertical one.

The **thin-film evaporators** constitute still another type of indirect multiple-effect evaporator. By forcing a small stream of liquor into the hot tubes, it boils immediately, and the whole machine is filled with foam that passes rapidly through the tubes. Entrainment (carrying over) of liquid particles in the

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steam, to which this type is particularly liable, is prevented by special catch-alls. The main feature of this type of evaporator, which may have either horizontal or vertical tubes, is the speed with which the machine can be started or shut down, the time for the liquor to go through the whole machine being only a few minutes, and comparatively little liquor being present at any one instant. This type of evaporator will soon get dirty inside the tubes; but it is easily cleaned, and very quickly, by running water through them instead of liquor. An evaporator of this type is described in greater detail in the Section on *Soda Pulp*.

QUESTIONS

(1) Explain the principle of the disk evaporator.

(2) What should be the concentration of the black liquor fed to the disk evaporator?

(3) Why is evaporation necessary?

(4) Trace the course of the black liquor, both as liquid and vapor, through a quadruple-effect evaporator.

(5 What are the advantages of the high-pressure evaporator as compared with the low-pressure evaporator?

(6) What is meant by *entrainment*, and how is it avoided?

THE FURNACE ROOM

THE ROTARY FURNACE

99. Outline of Process for Treating Black Liquor.—When the black liquor leaves the evaporators (whatever the type), it still contains a considerable quantity of water, the removal of which was originally a difficult and laborious task, because of the trouble offered to handling the tough, sticky mass that is formed by black liquor of high density. By adopting the rotary furnace *B*, Fig. 23, for this final evaporation, a better black ash is obtained and the labor cost is reduced considerably.

The lumps of dry, or nearly dry, black liquor (black ash) that are delivered from the rotary furnace contain the main portion of the organic substances from the wood and the inorganic salts, more or less changed, from the white liquor. This black ash is mixed with the necessary quantity of salt cake, Na_2SO_4, and is burned in the smelting furnace *C*, Fig. 23. The combus-

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tion gases from the smelting furnace are led through the rotary *B*, where a part of their heat is used for the final evaporation. In the smelter, the combustible part of the black ash is burned out and the chemicals smelted (melted), the resulting smelt being let out continuously through the bottom. The carbon acts as a reducing agent, and the salt cake is mostly converted into sodium sulphide; thus,

$$Na_2SO_4 + 2C = Na_2S + 2CO_2$$

The escaping smelt, which is now free from carbon and organic matter, is led over a spout into the dissolving tank *M*, from which the resulting solution, the green liquor, at a certain concentration, is pumped to the causticizing tank in the liquor room.

100. The Rotary Furnace.—The rotary furnace *B*, Fig. 23, is formed of a riveted sheet-iron cylinder, or shell, of very strong construction. The cylinder is open at both ends; the opening in the front end of the rotary is 3 feet less in diameter than the diameter of the cylinder, and in the back end it is 4 feet less. The cylinder itself is made in various lengths and diameters, some manufacturers preferring a longer rotary, which makes it possible to secure a little greater evaporation in the rotary and deliver the gases somewhat cooler to the disk evaporator, if there be one. Rotarys up to 30 feet in length are used in sulphate mills for making black ash, though ordinarily the length is between 20 feet and 24 feet; the diameter is seldom less than 8 feet, 9 feet to 10 feet being the common size.

101. Description of Rotary Furnace.—Referring to Fig. 23, the inside of the rotary *B* is lined with brick, to protect the shell from the action of the hot, burning gases and from the chemicals, in case the ash should get on fire and smelt. The lining is generally 8 inches thick and is cylindrical, like the shell. It is advisable to make the entire lining of firebrick, or, at least, for one-half the length of the shell next to the smelting furnace, the temperature there being very high.

On the outside of the rotary are attached two heavy steel tires *T*, placed about one-fourth the length of the shell from either end. These tires rest on strong cast-steel truck wheels *D*, two for each tire. The wheels have flanges, the distance between the inside edges of which is about ½ inch greater than the width of the tires; they keep the rotary from sliding, but allow a little play, horizontally. In some cases, instead of flanged wheels, the

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wheels are blank, and guide wheels are placed on either side of one of the tires. The rotary is caused to revolve by connecting two of the supporting wheels one on each tire, by a shaft, and then driving this shaft; the friction between the tires and the driving-supporting wheels causes the rotary to turn. Or, as shown in Fig. 23, a big gear *E* surrounds the rotary and is securely fastened to the shell; this gear should have plenty of air space, to avoid being heated excessively, and is made in sections, which can easily be removed. Gear *E* is driven by the pinion gear *G*.

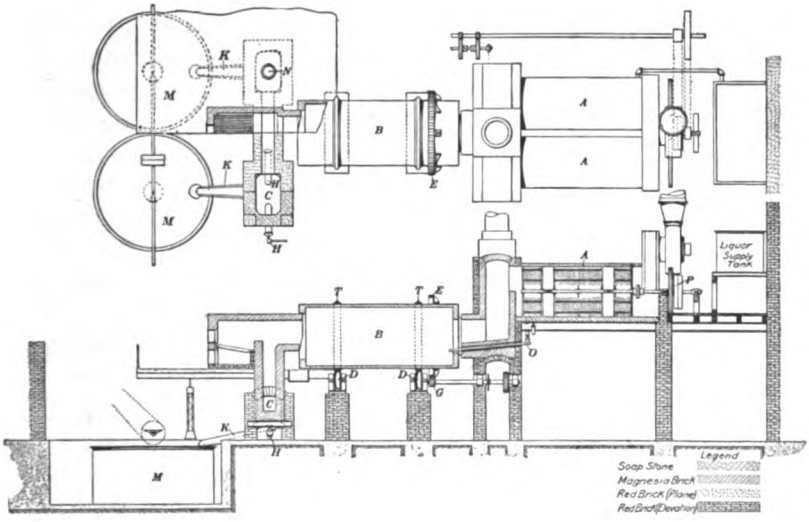

FIG. 23.

Of the two methods of driving the rotary, the first (which is not so common as the other) is the cheaper and is just as satisfactory.

To reverse the motion of the rotary, which is desirable in the case of a double furnace (one made with two fire boxes), two loose pulleys and a fixed pulley between them are placed on the shaft of pinion *G*; two belts are used—one open and one crossed—both driven by the same pulley, which has a width of face equal to the combined width of all three pulleys on the shaft of pinion *G*. When the open belt is on the middle, or fixed, pulley, the rotary turns one way, and it turns in the opposite direction when the crossed belt is on the middle pulley. The same result can be obtained more cheaply and more conveniently, when an individual motor is used to drive the shaft instead of the pulleys and

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belts, by reversing the direction of the motor. Since an accidental stoppage of the rotary and also of the disk evaporators might prove fatal to their durability, they are sometimes driven by a steam engine, to guard against such accidents.

It is desirable that the rotary be placed high enough over the floor from which the smelting furnace is fired to give ample room for the discharged black ash. To avoid exposing the front supporting wheels to the hot ashes, their bearings should be protected by a retaining wall.

102. Although the purpose of the rotary furnace is to complete the evaporation of the black liquor, it fulfills another purpose of equal importance. Because of the manner of firing the black ash in the smelter, the gases that leave this furnace are rich in combustibles. When they leave the smelter, these gases are far above the ignition temperature, and the addition of air will make them burn with a long and hot flame. To operate most economically, the volume of air admitted to and mixed with these gases (secondary air) must be determined in the same manner as in every other case of combustion. The air could be supplied in the smelting furnace itself, above the burning ashes, in a manner similar to that in which secondary air is added in a Dutch oven; but, on account of the high temperature that is reached, this would have a tendency to shorten the life of the furnace and to increase the cost of upkeep. In the rotary furnace, there is always a cover of black liquor and ash to protect the lining; this lessens the danger for overheating the brickwork, and makes it more profitable to admit in front of the rotary the air needed to complete the combustion. Air leaks in at the front end of the rotary and also in the back end, but this cannot be avoided. The temperature of the gases leaving the rotary, especially if the furnace is very long, might not be high enough to permit further combustion (even if there are any combustibles left), for which reason, the air leaks at the back end should be kept at a minimum. At the front end, where the ashes are discharged, baffles should be so arranged as to allow the admission of only just the volume of air that will give the final most advantageous results. Consequently, it is necessary not only to control the rate of combustion but also to check up the temperature of the gases after they leave the apparatus, with a view to utilizing their heat. The average installation will probably show the best results when the flue gases show no carbon monoxide

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CO or hydrogen and contain 11%–14% carbon dioxide CO_2. To obtain these results, it is essential that a certain definite draft be maintained in the back end of the rotary; a poor draft will most radically diminish the efficiency of the furnace installation, considering both heat economy and capacity. Too much draft will injuriously affect the output of the furnace unit, especially of the disk evaporator, but this bad feature is always more easily remedied. A draft of $\frac{1}{4}$ inch of water at the back end of the rotary, measured on the level of this furnace, will give best results, as a rule; more or less than this may give better economy, the best draft pressure being determined in each individual case.

103. Density of Black Liquor.—The black liquor, which is fed into the rotary at the back and, preferably, through a jacketed and water-cooled pipe *O*, Fig. 23, should be of high enough density to make good black ash without requiring any extra fuel in the smelter. Under ordinary conditions, black liquor in the kraft-pulp mill, testing 28°–32°Be., hot, corresponding to 31°–35°Be. at 60°F., will prove satisfactory; but, in case the black liquor carries a large amount of inorganic matter, it will be necessary to carry the test higher.

Poor black liquor will never give the satisfactory results; and it not only necessitates extra fuel for the fire in the smelter, which is bad economy even under the best conditions, but it also causes the rotary to ring up (become coated) inside with black ash, which might finally make it impossible to make any progress whatever. The resulting black ash is also very poor,—light and dusty,—which makes it troublesome to burn in the smelting furnace; it also causes unduly large losses of chemicals, which are carried away with the gases and through the flues.

The best black ash looks still a little moist, and it comes out in rather heavy lumps or porous masses, which burn well in the smelter. When burned, such black ash will give out 4000–5000 B.t.u. per pound. The speed at which the rotary revolves influences the appearance of the black ash; too fast a speed will usually produce a finer ash. For a 10-foot diameter rotary, one revolution every 50–60 seconds will be satisfactory.

104. Chemical Changes.—Certain changes in the constitution of the chemicals, which started in the disk evaporator (if there is one), occur in the rotary furnace. The carbon dioxide in the

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gases of combustion combines with the free sodium hydrate in the black liquor, and also engages sodium combined with the weaker acids. The organic ingredients are melted, and a destructive distillation of them is partly started, the volatile carbohydrates that result taking fire immediately. This distillation is avoided as much as possible, in order to maintain a reducing atmosphere in the smelter.

105. Adding Salt Cake.—The salt cake Na_2SO_4 that is used to make up the losses of chemicals during circulation, is mixed ordinarily with the black ash, or it can be added to the liquor before it is charged to the rotary. It would seem as though the latter practice possesses several advantages; and the perfect mixture that will be obtained in this manner ought to bring about a better reduction of the sulphate and, in addition, eliminate the losses of salt cake that are due to dusting.

The usual practice is to mix the salt cake with the black ash from the rotary while the ash is being shoveled into the smelter. By keeping daily records of the analyses and stocks of the liquor, it will be at once manifest whether the proper amount of salt cake (or niter cake) is being used. A certain fixed quantity of salt cake is fed per hour to each smelter as uniformly as possible, carefully mixed with the black ash; the weight of salt cake is then varied as may be deemed necessary, according to the quantity of liquor on hand. Any deficiency of the liquor stocks should rapidly be made up for by adding more salt cake than usually; an investigation should also be started, to determine the cause of the undue losses of chemicals.

106. Niter Cake.—It has recently been proposed to substitute niter cake for salt cake in replacing the losses of chemicals. Niter cake is a product in the manufacture of nitric acid, where Chili saltpeter, sodium nitrate $NaNO_3$ is treated with sulphuric acid H_2SO_4, to obtain nitric acid HNO_3. In addition to the nitric acid, a product called niter cake is obtained, which has a formula closely corresponding to $NaHSO_4$; $NaNO_3 + H_2SO_4 = NaHSO_4 + HNO_3$. The excess sulphuric acid can be driven off by heat and salt cake obtained, in accordance with equation (1), or it may be neutralized by sodium hydrate, in accordance with equation (2); thus,

$$2NaHSO_4 + \text{heat} = SO_3 + H_2O + Na_2SO_4 \qquad (1)$$

$$NaHSO_4 + NaOH = Na_2SO_4 + H_2O \qquad (2)$$

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The result of the two reactions is the same insofar as the alkali is concerned; but the first reaction gives sulphuric anhydride, which readily forms sulphuric acid, and the acid may damage machinery and vitiate the air. The acid may react with any sodium compound forming sulphate; thus $NaCO_3 + H_2SO_4 = Na_2SO_4 + H_2O + CO_2$. If such reaction occur with a sulphide, hydrogen sulphide, H_2S, a poisonous gas, is set free; thus,

$$Na_2S + H_2SO_4 = Na_2SO_4 + H_2S$$

Niter cake should *never* be added to the smelt dissolving in the causticizing tanks. There have been at least two instances where men were killed when niter cake was used, presumably by hydrogen sulphide.

107. In the sulphate-pulp mills, where the losses of chemicals are low, the percentage of sulphides in the regenerated liquor will be correspondingly small, since a large portion of the sulphur is lost in the process and new sulphide can be formed only from the sulphate at hand in the smelting furnace. It is desirable to maintain a high percentage of sulphide in the white liquor for several reasons: the product of the cooking will be of better quality, the yield of the wood will be larger, and the quantity of lime used per ton of pulp manufactured will be smaller, if the white liquor contain a larger proportion of sodium sulphide as compared with the sodium hydrate. By substituting niter cake for salt cake, the result will be the same as though nearly double the quantity of salt cake had been used, as concerns the possibilities of obtaining sulphide in the liquor; but, at the same time, the quantity of fresh sodium that is given to the liquor is just sufficient to maintain the liquor stock.

To make the use of niter cake possible, it is added to the black liquor as it enters the rotary or immediately before. The niter cake, which usually comes into the market in big blocks, is crushed in a stone crusher into rather small lumps; these are fed into the rotary, where a rapid reaction takes place, with the formation of carbon dioxide and also small quantities of hydrogen sulphide H_2S. There is likewise some water formed in the reaction, which has to be allowed for by using a correspondingly higher concentration of the black liquor. The volume of gases formed is comparatively small, and it will scarcely affect the heat economy of the installation. This process is patented; it has not as yet been operated for any length of time, and it is

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hard to say whether the results will be satisfactory. However, it appears to be feasible.

The furnace room should be well ventilated, particularly, if niter cake is used.

108. Composition of Black Ash.—The black ash that is discharged from the rotary furnace contains the inorganic chemicals from the cooking, more or less changed in their constitution, and also the organic matter derived from the wood, but is practically free from water. The composition of the black ash is dependent on so many factors and varies so much with the conditions, that it is hard to give an average analysis; but good black ash should contain about 50% combustible matter. If not already mixed with the necessary quantity of salt cake, this is now added to the black ash, and the mixture is shoveled into the smelting furnace, the work of which is of great importance to the success of the process, and must be guided carefully to give proper results. It is not only a question of burning fuel to the greatest possible advantage but also to obtain a grade of smelt that fills the requirements and to avoid the sublimation of chemicals through excessive heat.

THE SMELTING FURNACE

109. Description of the Smelting Furnace.—In Fig. 24 is shown a combined partial front view and cross section, a vertical section, and a top view of a **double smelting furnace.** Partition *a* separates the two hearths *F*, *F*. Black ash from the rotary *B* is mixed with salt cake on the platform at *P*, and is shoveled into the furnace through the fire doors *N*. The gases pass into the common flue *Q* and through the throat *Q'* to the rotary. The smelt—the fused mass of sodium carbonate and sulphide—flows out through spout *K* to the dissolving tank *M*. Air for combustion of the fuel and the carbon in the black ash is introduced through the nozzles *H*.

The smelting furnace *C*, Figs. 23 and 24, is built of some refractory material, which must also resist the action of the smelting sodium salts. Soapstone is the material generally used for the lining of the bottom and side walls of the fireboxes, and also for arches and flues. Chrome brick has also been used in building smelters; though a very expensive material, the better service given by it is said to justify the increased cost.

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110. Temperature of Furnace.—To ascertain the most economical temperature at which to run a smelting furnace lined with soapstone, a series of laboratory tests was conducted. A full account of these tests appeared in *Pulp and Paper Magazine*, Vol. 19, of which the following is a summary:

The fusion (melting) temperature of soapstone was found to be 1400°–1450°C. (2552°–2642°F.).

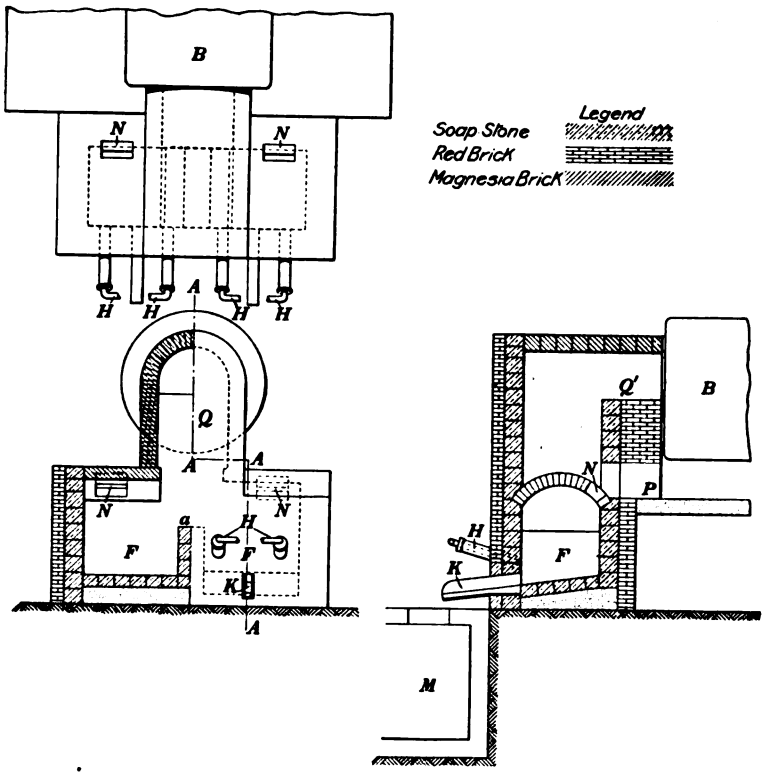

FIG. 24.

Action of fused sodium hydrate: After 15 minutes at 325°C. (617°F.), no evidence of any action could be noted; no action was noted until a temperature of 1250°C. (2282°F.) had been reached.

With superheated sodium carbonate, slight action was noted after 15 minutes at 1200°C. (2192°F.), and considerable action was noted after after 15 minutes at 1250°C. (2282°F.).

The lowest temperature at which the black ash could readily be reduced and fused was 900°C. (1652°).

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Comparing these purely laboratory tests with practical tests made in an American sulphate mill, the lowest temperature mentioned in the laboratory tests (900°C. = 1652°F.), the lowest temperature at which black ash could be reduced, was found not to be practical in a mill; such a low temperature cannot exist, at least for any length of time.

At the mill, the tests were undertaken to ascertain whether or not a furnace would operate satisfactorily at a temperature between 2000°F. and 2500°F., it being realized that if such a temperature could be maintained, soapstone would be saved and the life of the furnace would be greatly prolonged. The test was also made with a view to avoiding excessive temperatures; because this particular mill had trouble with the black ash melting in the neck of the furnace, which obstructed the free passage of the gases. It was thought that by operating at a more uniform and lower temperature, this trouble might be overcome.

It has been found that the furnace will operate successfully at about 2000°F. Due to the black ash being hand fired, the temperature will vary greatly, according to the manner in which the firing is done. There are many factors, such as the depth of the furnace and other practical details, which must be taken into consideration. It is a fact, for instance, that the hottest place in the furnace, which might be called the "melting pot," changes its position quite frequently during firing; black ash will come down directly in front of the blow-pipes, altering the direction of the air a little, which immediately changes the position of the melting pot.

The more evenly the furnace is fired the less is the excess heat required; it will be found that in most mills, about 2000°F. is a good temperature at which to operate the furnace.

111. Construction of Smelting Furnace.—Whatever the material used in the construction of the furnace, it is essential to have good, tight joints and to avoid the use of much mortar. The mortar is made from fire-clay; it should be so thin that when the stone to be laid is dipped into it, only a thin film of clay will stick to it, the stone being driven into place very solidly. The arches should not be built too flat; that is the part of the smelter which usually gives out first, and a flat arch is more liable to fall in when getting thin than a higher arch. The fire resistant lining is encased in brick work (usually, red brick), the purpose of which is to make the construction more solid and to tighten up

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eventual cracks in the lining. The whole construction is heavily reinforced, to keep it from opening up through uneven contraction and expansion. The bottom of the firebox *F*, Fig. 24, is made to slope, to allow a speedy drainage of the smelt. It is of great importance that the smelt find its way out readily, in order to prevent re-oxidation of the sulphide and to avoid filling up the bottom of the firebox with smelt, which might block the air nozzles *H*. To keep the smelt from staying too long in the firebox, the sectional area of the firebox should not be very large, and the smelting zone of the chemicals should be centralized close to the opening through which the smelt leaves the furnace.

The smelting furnace is built either with one firebox (a single furnace) or with two fireboxes (a double furnace). The single furnace is easier to build and will cost less in up-keep; but the capacity of the machinery attached to the smelting furnace, the rotary furnace, and the disk evaporator, is not so well utilized as with a double furnace. The output of a single-furnace unit corresponds to about 18 tons of pulp at its best, while black ash sufficient for 30 tons or more of pulp may be burned in a double-furnace unit, if forced. It will be more economical however to run the furnace slower and be satisfied with an output corresponding to 22–25 tons of pulp per 24 hours, for a double furnace.

112. Air Nozzles.—The air to the smelting furnace is usually forced into the firebox through **air nozzles** *H*, Fig. 24. The air nozzles are preferably water-jacketed, the life of an uncooled pipe in the firebox being very short, and care should be taken to place the water outlet at the highest point of the nozzle, thus keeping it from getting air bound. The inlet water is carried to the lowest end of the nozzle by means of a pipe inside the jacket. The water admitted is usually cold, although, in some instances, it is pre-heated; the return water may with advantage be used for boiler feed water. The location of the nozzles, their number, and the pressure of the air supplied to them, depend on what capacity is expected of the firebox.

When a small output of smelt is expected, the air nozzles should be placed rather steeply, on an angle of about 30°, in the front of the firebox, well drawn together toward the opening for the smelt, and should not be inserted too far into the smelter. In this manner, it will be possible to keep the nozzles and the spouthole open with but a low pressure of air (2 to 3 inches of

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water), the volume of air supplied being correspondingly small; two nozzles is then the usual number.

When it is desired to maintain a large output of smelt, the air must be supplied under increased pressure. The smelting zone in the firebox must be larger; and in order to obtain this result and also to avoid blowing the flame and ashes out through the smelt outlet,—the spouthole,—the air nozzles must be set farther apart. A third air nozzle may be installed in the back wall of the firebox, with the double purpose of making the smelting zone larger and of keeping the spouthole open. It is desirable to have a small flame come out through the spouthole. To preserve the lining of the bottom and to avoid exposing the smelt to the air, the nozzles are set flatter than when the desired output is small, the angle being about 20°. To protect the walls, the nozzles are also inserted farther into the firebox, the point of discharge being usually 14–16 inches inside the wall. By placing the nozzles in the side walls of the firebox, the smelting zone is carried to the middle of the smelter; but this arrangement makes it necessary to carry a very high pressure on the nozzles, and they must be placed at a steep angle to keep them from plugging up; since the distance from where the smelt is formed to where it is discharged is somewhat great, and the flow might easily be stopped.

113. The Spout.—When the smelt leaves the furnace, it is led over a spout K into a dissolving tank M, Fig. 24. The spout is generally made of the same material as the lining of the smelter. The spout is subject to mechanical wear and chemical action of the running smelt, and also to the wear caused by the bars used to keep it open and clean; hence, a spout of this material requires renewal at frequent intervals. Better service will be obtained from a cast-iron or cast-steel spout that can be bought in the market; but special attention must then be given to fastening the spout in the brick work, to keep it from working loose. A long spout gives considerable trouble in starting up the smelter; the smelt is not then hot enough and does not discharge in sufficient quantity to keep running all the way over the spout. But once the smelter is running, a long spout gives the smelt a chance to cool off somewhat before it drops into the dissolving tank, thus avoiding to a certain extent the splashing that occurs when the hot smelt hits the liquor. On the other hand, too long a spout may cause re-oxidation of the sulphide.

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114. The Dissolving Tank.—The dissolving tank *M*, Figs. 23 and 24, consists of a strong, riveted-plate cistern, equipped with an agitator on a vertical shaft. The arms of the agitator are long enough to keep any smelt from accumulating in the tank underneath the spout; they are usually arranged with a drag that reaches well down toward the bottom. The top of the tank is covered with sheet iron, and the drive for the agitator is generally placed on top of it. The drive should be as much out of the way as is possible, so it will not hinder the work of the men opening the spouthole or the nozzles in front of the smelter. If the tank be placed somewhat underneath the smelter and considerably lower than the discharge of the spout, the smelt will be delivered more to the center of the tank; it will then cool off more when falling, which will reduce the splashing and the accompanying losses. The sheet iron of the tank will also be preserved, since it will not be exposed to the action of the smelted chemicals.

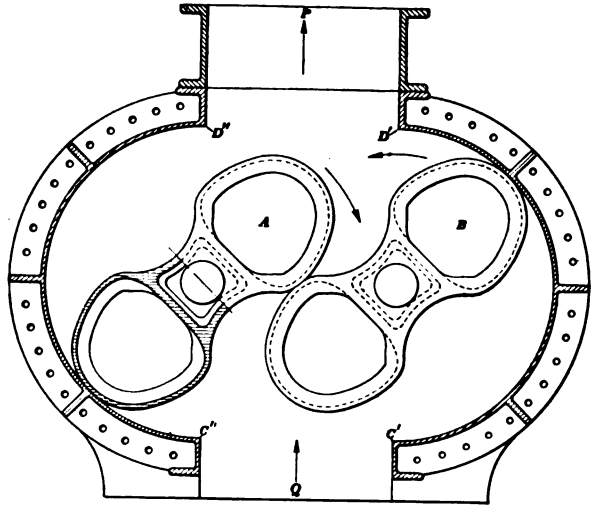

FIG. 25.

115. The Air Supply.—The air for the nozzles in the smelter is supplied by a blower or a powerful fan. Fig. 25 is a cross-section of what is called a **positive pressure blower.** The impellers *A* and *B* rotate in opposite directions, delivering the air upward in this case. The clearance is very small, and there is, therefore, but little leakage. In the figure, the upper wing of

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B has almost finished delivering its charge, while the lower wing of *B*, revolving toward *C'*, is about to confine a new volume, practically all of which will be delivered at *P* when the wing reaches *D'*, regardless of what pressure exists in the discharge pipe *P*. In the position shown, the upper wing of *A* has discharged its load into *P*, and the lower wing is beginning to deliver. When a wing pushes out air in front of it, it leaves a partial vacuum behind it, and this causes a rush of air through *Q* to fill the vacuum thus created.

116. Fig. 26 shows a **fan** in part section. Air is drawn into the casing *A* through a central opening. Vanes *B* on the spider

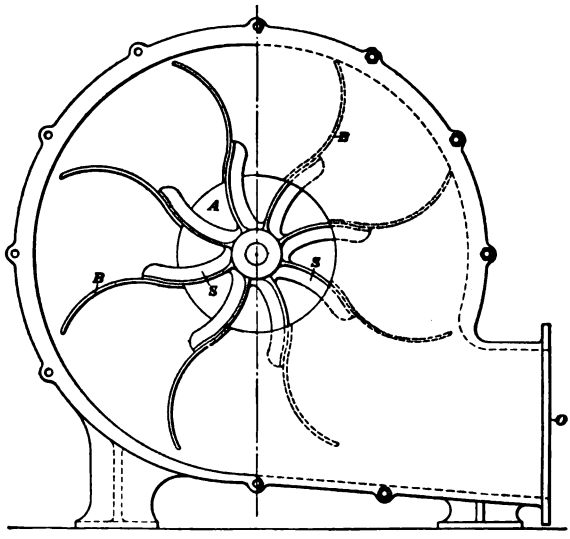

FIG. 26.

S whirl the air around and deliver it by centrifugal force tangentially against the casing, which is designed to discharge it with the least loss of energy at *O*. The volume and pressure of the air discharged may be varied by altering the speed of rotation.

The blower, Fig. 25, is a more expensive installation than the fan, Fig. 26, but it has the advantage of being able to deliver the air at a higher pressure than the fan. The volume of air supplied to the smelter should be well controlled, as it is essential to maintain a reducing atmosphere in the firebox. The air supply may be limited in one of two ways: use an air nozzle of small diameter

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and supply the air under high pressure; use a pipe of larger diameter and decrease the velocity (and pressure) of the air. Experience has shown that it is difficult to keep open an air nozzle of small diameter under any conditions, for which reason, it is not advisable to use a nozzle smaller than 3 inches.

117. Pressure of Air Supply.—In case the smelter is run at a high rating, the firebox will always be kept full of ash, and there is a certain amount of danger of getting the nozzles plugged up with ashes; but still worse conditions will arise, if the spouthole gets plugged up and the flow of smelt is partly shut off. The firebox might then gradually fill up with smelt, without anyone noticing it. With the air nozzles in front of the smelter, the best results have been obtained with an air pressure of 4–7 inches of water at the back end of the nozzle, when discharging freely. If this nozzle should become blocked with ash or if the smelt should rise to the level of the nozzle, this air pressure is not sufficient to keep the nozzle clear; it will then get plugged or partly blocked, which will decrease the output of the smelter, and it will be a difficult and tedious job to remove it, if the plug is caused to smelt. If the air be supplied by a blower, it is possible to carry considerable pressure on the main line, say 20–24 inches of water; by having individual gate valves on each nozzle, with which to regulate, the desired pressure is obtained on the nozzle. If, now, the discharge gets blocked, the pressure is automatically increased to that on the main, and the danger of complete plugging is practically removed, the pressure of the air being sufficient to blow away the obstruction. Pressure gauges on each individual nozzle will then at once indicate whether the passage is free or not, and the attention of the operator will be called to any irregularity.

118. Operation of Smelting Furnace.—The object of the work in the smelting furnace is to remove the organic substances and to reduce the salt cake (sodium sulphate) mixed with the black ash to sodium sulphide. As previously stated, the sodium sulphate is of no value in the process of digesting wood; as in the case of sodium carbonate, it is only dragged around in the cycle of operations without doing any good, always giving chances for loss of chemicals. The following equation shows the reaction by which the salt cake is reduced to sodium sulphide:

$$Na_2SO_4 - 4O = Na_2S$$

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It will thus be understood that it is desirable to avoid the presence of sodium sulphate in the white liquor, and that the above reaction should be effected as completely as possible in the smelter. To obtain this result, the furnace work must be watched very closely; and since the quality of the smelt is dependent to a very large extent upon the volume of the air and the place where the air is admitted to the smelter, the conditions under which the best results are obtained will have to be determined. About 1500 cu. ft. of air per min. should be sufficient for a double furnace in a 30-ton mill.

Different arrangements of the air nozzles and different ways of firing the smelting furnace call for a different pressure of air for the nozzles. Also, the same results can be obtained in different ways; but once the method is chosen, the object is to determine how to secure the best results from it. The present tendency is toward fewer and larger nozzles, with lower velocity of the air, to reduce the intensity of the heat in the locality where the air is discharged. Some recent installations have only one nozzle, 6 inches in diameter, which enters the firebox at the center, through the top, and is so arranged that the level of the air discharge can be changed without interrupting operations. The conditions that will permit the largest output of smelt with the smallest cost of up-keep, and at the same time, result in the least loss of chemicals and the best heat economy, is what must be determined.

119. A furnace of small capacity, corresponding to 8 to 10 tons of pulp per firebox, is run with low pressure on the nozzle, the air pressure at the back end of a nozzle 5 to 6 feet long being only 2 to 3 inches of water. When running the furnace in this manner, it is necessary to avoid filling up the fireboxes with black ash; the ash is fed into the smelter from behind, the opening of the nozzles is barely covered with ash, and the smelting zone is close to the spouthole. The temperature that is obtained in this way is not very high, which results in a lower up-keep of the smelter and also reduces the losses of chemicals due to sublimation. The fireboxes are of rather small dimensions, with a good sloping bottom, so that the smelt, which is of high viscosity owing to the low temperature, may run out rapidly.

A larger capacity per furnace unit is obtained by using a higher pressure of air on the nozzles, when smelt sufficient for 14–15 tons of pulp, or even more, can be made in one firebox. At the

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same time, however, the temperature in the firebox is increased, which is accompanied by larger losses of chemicals, and the life of the smelter is shortened. The temperature is considerably higher than when operated at low pressure, and may reach to 2200°–2300°F. or higher. To make the furnace last a reasonable length of time under these conditions, it is necessary to centralize the high temperature zone, to avoid heating the lining to such a high degree, and it is also necessary to keep the fireboxes full of black ash all the time. The hot gases from the smelting zone will then have to pass through a thick layer of black ash before striking the walls and arches of the smelter; in this layer, a destructive distillation of the ash occurs, which lowers the temperature of the gases considerably.

120. The gases leaving the smelter are rich in combustibles, and sufficient air must be supplied to the rotary furnace to complete the combustion. The ash thus distilled finally comes down to the smelting zone, where it is supplied with air; it then consists of but little else than carbon and inorganic chemicals, all the volatile carbohydrates having been driven off. A part of the carbon is burned in the smelting zone, supplying heat to smelt the chemicals, and the remainder is absorbed by the molten mass. At the temperature there existing, this remaining part of the carbon acts to reduce the sodium sulphate, when any one of the reactions indicated in the following equations may take place:

$$Na_2SO_4 + 4C = Na_2S + 4CO \qquad (1)$$
$$Na_2SO_4 + 2C = Na_2S + 2CO_2 \qquad (2)$$
$$2Na_2SO_4 + C = 2Na_2SO_3 + CO_2 \qquad (3)$$

In addition to the foregoing reactions, others are liable to occur, of which the more important are:

$$2Na_2S + 3O_2 = 2Na_2SO_3 \qquad (4)$$
$$2CO + O_2 = 2CO_2 \qquad (5)$$

At the temperature that exists in the smelting zone and under the conditions that it is desired to maintain, the reaction of equation (1) is the one most likely to dominate. If the reducing reaction takes place below the smelting zone, where the temperature is somewhat lower and the air supply has been sufficient to burn out the carbon more completely, the reaction of equation (2) might govern. The reaction of equation (3) is caused either by an excess of air or by too low a temperature. The reaction of equation (4) will occur if the smelt, hot or cold, is exposed to

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the air; from which it will be seen that it is of great importance that the smelt be rapidly removed, to avoid re-oxidation of the sulphide, which will result in the formation of sulphite. The reaction of equation (5) will take place at a lower temperature and with an excess of air.

A large content of sodium sulphite in the smelt is thus caused by either too much or too little air; which is the cause is easily decided when the conditions under which the furnace operates are known. Whatever the reason is for an undue percentage of sulphite, the fault should be remedied, since it reduces the economy of operation of the furnace; the sulphite is of no value in the digester, and its presence in undue amount indicates usually the presence also of a high percentage of sulphate.

Thus it is desirable to avoid too low a temperature, but it is just as much of a detriment to keep the temperature too high. About 1700°F. is the lowest temperature at which the salt mixture will smelt; but to operate efficiently, the temperature will have to be considerably higher. At a temperature of about 2000°F., the most satisfactory results will probably be obtained, considering both the conservation of chemicals and the preservation of the furnace lining. When a large capacity is wanted from the smelter, the temperature will go higher; but, at no time, should it be allowed to go higher than 2200°F. If a still larger production be wanted than can be obtained at this maximum allowable temperature, it will undoubtedly be more economical to increase the recovery-room equipment. When the temperature in the smelter is excessive, chemicals may be sublimed or mechanically carried off in the furnace gases and deposited in the flues or elsewhere; this is a source of much loss to the mill.

121. Such impurities in the smelt as the silicate and aluminate of soda are to be avoided, because of the trouble they give later on in the settling tanks, the precipitates derived from them being very voluminous and keeping the lime sludge from settling. The main source of these impurities is the lining of the smelter, and in order to reduce them to a minimum, it is necessary to keep the furnace walls as cool as may be, which is accomplished by keeping the fireboxes full of black ash.

A smelter designed to work with a high pressure on the air nozzles has larger dimensions than the slow-running, low-pressure type. The sectional area is usually 5 × 5 feet or 6 × 6 feet,

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and the height at the top of the arch is generally 7 feet, the dimensions being such that there is plenty of space for black ash, to protect the lining.

When permitted to cool, the smelt that leaves the furnace will often indicate by its appearance whether it is of good or of poor quality. The color of a cooked lobster in hardened smelt indicates a high percentage of sodium sulphide and a correspondingly good reduction; whereas a smelt of yellow tone, as a rule, contains an excessive quantity of sodium sulphate. The composition of smelt will, of course, vary much under different conditions. The following analysis is that of a good smelt:

Na_2CO_3	64.95%
NaOH	0.61%
Na_2S	20.38%
$Na_2SO_3 + Na_2S_2O_3$	1.08%
Na_2SO_4	6.73%
Na_2SiO_3	3.25%
Insoluble	2.57%

122. Waste and By-Products.—The present method of utilizing the organic matters in the black liquor, that is, by burning them to generate heat, seems rather crude and wasteful, and several attempts have been made to recover the inorganic chemicals while, at the same time, saving the valuable organic substances; but none of these methods have as yet been economically successful. It is, however, probably only a question of time when, instead of burning them up, valuable products will be obtained from these organic substances, either by carefully splitting them up or by adding to them.

123. Starting the Furnace Room.—When a smelter unit is first started up, the disk evaporator is filled to the proper level with evaporated liquor of a density greater than that ordinarily used for the purpose, about 25°Be. The fireboxes are filled with wood, and the blow nozzles are opened to admit the air. When the smelter and rotary are sufficiently hot and the test of the liquor in the disk evaporator is up to 28°–32°Be., hot, liquor is gradually let into the rotary, so that the rotary is kept wet at the back and the liquor does not run over in the front. In due time, the rotary will begin to discharge black ash at the front. The firing with wood is continued until a sufficient quantity of black ash is obtained to fill up the fireboxes, when ash mixed with salt cake is fired instead of wood.

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QUESTIONS

(1) What operation is required in the recovery department of a sulphate mill?

(2) Referring to Question (1), state the purpose of each machine.

(3) How does smelt differ from black ash?

(4) (*a*) Why is the use of niter cake sometimes dangerous? (*b*) What precautions should be taken?

(5) What may happen to the smelt if the spout is too long?

(6) (*a*) How do impurities get into the smelt? (*b*) why do they cause trouble?

APPENDIX TO SULPHATE PULP

METHODS OF ANALYSIS

ANALYSIS OF SMELT

Note.—Those students and readers who do not possess a fair knowledge of the ordinary methods of chemical analysis, particularly of volumetric analysis, are advised to omit this Appendix, except Arts. **18–23**, and no questions relating to it are given in the Examination Questions. To those who have this knowledge and have access to a chemical laboratory, it is suggested that they perform the various analyses herein described, following strictly the directions given.

1. Remark.—The manufacture of sulphate pulp is very much a chemical process, and the successful operation of the mill depends to a great extent on the nature of the chemicals produced in the different stages of the process. It is therefore of great importance that the constitution of these products be known and that the quantities of the various substances composing them be checked from time to time. In this way only, will it be possible to establish conditions under which the most favorable results in operating the mill can be obtained at least expense. It is to be noted, however, that those results which give entire satisfaction in one mill will not necessarily be what is wanted in another mill, where conditions are different. For any particular mill, once it has been determined what results are wanted, a most careful control must be maintained, to make certain that these desired results are always obtained.

The analysis of raw materials, such as coal, salt cake, and lime, are of great importance, of course, and should not be neglected; but, since standard methods for analyzing these products are

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given in the Section entitled *Analysis and Testing of Raw Materials*, they are omitted here. A complete analysis of all the mill products can be performed only by a trained chemist; but several analyses, which are of great value to the successful operation of a mill, can be performed by the layman, using only the very simplest of laboratory apparatus, and these will be explained in the following pages.

2. The Smelt Soda.—The analysis of the **smelt soda** or **smelt** (fused mass from the smelting furnace), which contains quite a number of different compounds of sodium and, in addition, impurities derived from the furnace lining, is a complicated matter; it is made more difficult because of the precautions it is necessary to take in order to avoid changes in the material that are due to the oxidizing action of the atmosphere. The result of the smelter work is therefore more easily controlled by analyzing the green liquor that results from dissolving the smelt in water. Furthermore, the sample thus taken for analysis covers a longer period of time and therefore gives better information concerning the work of the smelter. However, there may be cases when it is necessary to take a sample of the smelt at a particular time, and under the conditions then prevailing; in this case, a sample of smelt is taken where it is discharged from the furnace, it is pulverized rapidly, and then placed in a tightly-closed bottle, where it is left to cool off. After two or three samples have been taken in this manner, they are carefully mixed, and one sample is taken out of the mixture for further treatment. This sample is now ground up sufficiently fine, as rapidly as possible, and about 50 grams is placed in a closed weighing bottle, the weight of which is known. After obtaining the weight of the sample, it is brought into solution in distilled water, the water having first been freed from carbon dioxide, CO_2, (traces of which are usually always present) by boiling. The sample is preferably dissolved in a 1000 c.c. measuring flask, the long, narrow neck of which prevents the admittance of air. When the smelt is entirely dissolved, the solution is left to cool off to the temperature of the room; it is then diluted to the mark, and is carefully mixed, so the smelt will be evenly distributed throughout the solution.

The smelt, prepared as above described, is usually analyzed for its content of sodium sulphate Na_2SO_4, sodium sulphide Na_2S, and, if desired, sodium sulphite Na_2SO_3. The relation

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between these three compounds is a guide as to whether the furnace has been working properly. In connection with the sulphate process, these three substances are frequently referred to as *sulphate*, *sulphide*, and *sulphite*, respectively, the word sodium being understood.

3. Determination of Sodium Sulphate.—If a material be examined for the purpose of ascertaining the amount of a single substance (or element) contained in it, the result is called a **determination**; but if the material be examined to determine several the substances and their amounts, the result is called an **analysis.** An analysis then, may be considered as the sum of two or more determinations.

To determine the amount of sodium sulphate, Na_2SO_4, in a smelt, prepare the solution as directed in Art. **2.** Note that when the flask was filled to the mark, it contained 1000 c.c. (= 1 liter) of solution, in which was about 50 grams of the smelt; hence, 20 c.c. of the solution contains $\frac{50}{1000} \times 20 = 1$ gram (very nearly) of smelt. Using a pipette, measure 20 c.c. of the solution into a beaker, and dilute it with some water. To this is added an excess of hydrochloric acid HCl, which should be run into the beaker slowly, drop by drop, from a pipette, the beaker being covered as completely as possible with a glass plate (watch glass), to catch any splashes caused by the escaping CO_2. This sample, which is now slightly acid, is washed into a porcelain dish and evaporated to dryness on a water bath, after which it is heated to 110°–120°C. for about 15 minutes. The residue (what is left in the porcelain dish) is then moistened with concentrated hydrochloric acid and heated once more to the same temperature as in the previous heating, to make the precipitation of silica SiO_2 complete. The residue is then dissolved in hot water and filtered. The filter is carefully washed with hot water, and the SiO_2 is left on the filter; its amount may be determined by burning the filter in a platinum crucible and weighing the residue. The molecular weight of silica SiO_2 is 60.3 ($28.3 + 2 \times 16$); the molecular weight of sodium silicate Na_2SiO_3 is 122.3; hence, one part of SiO_2 corresponds to $\frac{122.3}{60.3} = 2.028$ parts of Na_2SiO_3. The filtrate, which was made slightly acid by hydrochloric acid, contains the sodium sulphate, which is now isolated, by precipitating hot with a 10%

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solution of barium chloride $BaCl_2$, and allowed to boil for a few minutes. The precipitate, barium sulphate $BaSO_4$, is taken upon a filter and carefully washed with hot water, after which, the filter is burned (without preliminary drying) in a platinum crucible, and is heated to white heat, until the weight is constant. This precipitate of barium sulphate is then weighed. One part $BaSO_4$ (mol. wt. = 233.5) corresponds to 0.609 parts Na_2SO_4 (mol. wt. = 142.1), since $\frac{142.1}{233.5} = 0.609-$. Therefore, if the weight of barium sulphate as found be multiplied by 0.609, the product will be the weight of the sodium sulphate in 20 c.c. of the original solution, which, as shown above, contains 1 gram of smelt. Suppose the weight of sodium sulphate thus found is n mg. (milligrams); then, since 1 g. = 1000 mg., $\frac{n}{1000} \times 100 = \frac{n}{10}$ = per cent of sodium sulphate in the smelt. If the original quantity of smelt were larger or smaller than 50,000 milligrams, allowance has to be made when figuring the percentage.

4. Determination of Sodium Sulphide and of Sodium Sulphite. Measure out 20 c.c. of the original solution (Art. 2) in a pipette, bring it into a 200 c.c. measuring flask, and dilute with water to the mark. Of the solution so obtained, 20 c.c. (which contains $\frac{20}{200} = \frac{1}{10}$ gram of smelt) is diluted with about 200 c.c. of cold water in a beaker and is acidified with an excess of acetic acid. This solution is then rapidly titrated with a decinormal (tenth normal or $\frac{N}{10}$) iodine solution, using starch as an indicator. Both sulphide and sulphite (but not sulphate) are oxidized by the iodine. From the number of cubic centimeters of iodine solution used (= c) will have to be deducted the number of cubic centimeters (= d) used for the next test. The difference thus obtained multiplied by 0.039 will give the contents in grams of the Na_2S in the original 20 c.c. of solution; that is,

$$(c - d) \times 0.039 = \text{grams of } Na_2S$$

in 20 c.c. of the original solution.

This is arrived at as follows: Mol. wt. of Na_2S = 78, and the normal solution contains (since there are two sodium atoms) $\frac{78}{2}$ = 39 grams per liter = 0.039 gram per cubic centimeter;

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the solution titrated contained one-tenth gram of smelt; the iodine solution was one-tenth normal; hence, the proportions of the results are the same as though 20 c.c. of the original solution had been titrated with a normal iodine solution.

5. Another 20 c.c. of the original solution is mixed in a 200 c.c. measuring flask with a sufficient volume of an alkaline solution of zinc acetate[1] to react with the sulphide, in accordance with the equation

$$Na_2S + Zn(C_2H_3O_2)_2 = ZnS + 2NaC_2H_3O_2$$

The solution is then diluted with water to the mark. When the precipitate of zinc sulphide is settled, 20 c.c. of clear solution (which contains no sodium sulphide) is withdrawn with a pipette and, as in the previous test (Art. **4**), is acidified with acetic acid and titrated with decinormal iodine solution. The number of cubic centimeters of iodine solution used ($= d$) multiplied by 0.063 gives the content in grams of sodium sulphite in 20 c.c. of the original solution; that is,

$$d \times 0.063 = \text{grams } Na_2SO_3$$

in 20 c.c. of original solution. This is arrived at in the same manner as in the case of the sulphide, Art. **4**. Mol. wt. of $Na_2SO_3 = 126$; and, since there are two atoms of Na, the normal solution contains $\frac{126}{2} = 63$ g. per l. $= 0.063$ g. per c.c.

6. Of the original quantity of smelt taken as a sample and weighed out, $\frac{1}{50} = .02 = 2\%$ is contained in 20 c.c. of the original solution. Knowing this, the percentage of sulphate, sulphide, and sulphite is easily found when their weights in 20 c.c. of the solution are known. Or, the percentage may be found as described in Art. **3**, by dividing the weight in milligrams by 10.

The sulphate and sulphite should be present only in small quantities, since too large a content of these compounds indicates insufficient smelter work. Smelt that contains 20% Na_2S as compared with the presence of 1%–2% of Na_2SO_3 and 6%–7% Na_2SO_4 represents a reduction of about 80% of the available sodium sulphate into active sodium sulphide, which may be considered as a satisfactory result.

[1] In preparing this solution, made by adding NH_4OH to a 10% solution of $Zn(C_2H_3O_2)_2$, a precipitate of zinc hydrate, $Zn(OH)_2$, will form. Add more NH_4OH, slowly, with stirring, till the precipitate dissolves.

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ANALYSIS OF LIQUORS

7. Analyzing the Green Liquor (The Iodine Method).—All the constituents of the smelt are to be found in the green liquor. Therefore, an analysis of the green liquor, at the density wanted for the caustic room, is a better guide, as a rule, for control of the smelter work than an analysis of the smelt; because as previously stated, it gives an average sample of this product (smelt) over a long period of time. The different substances will not, of course, be in the same proportions in the green liquor as in the smelt, since the liquid used as a solvent contains a certain amount of liquor that has been already causticized. This will change the relation between the sodium hydrate and the sodium carbonate (*i.e.*, the ratio of the two), in favor of the hydrate, depending on the concentration of the liquor used for filling the dissolving tanks; it will also, to a lesser extent, have an influence on the other constituents. But, since the changes in the composition of the green liquor, as compared with the liquor resulting from dissolving smelt in pure water, are very nearly constant, so long as no changes are made in the operation of the liquor room, an analysis of the green liquor may be considered to be a safe method of following up the work of the smelter.

8. Determination of Carbonate and Hydrate.—In addition to the sulphide, sulphite, and sulphate, which have already been treated under the Analysis of Smelt, it is necessary to make determinations of the carbonate and hydrate in the green liquor, since these are the governing factors for the quantity of lime to be used to obtain the per cent of causticity.

When the volumetric method is used for analyzing the different solutions of liquor that are obtained in the sulphate mill, a standard solution—usually normal $\left(=\frac{N}{1}\right)$ or decinormal $\left(=\frac{N}{10}\right)$ in the case of an iodine solution—is employed to measure the concentration of the various constituents. Thus, the concentration of hydrate NaOH is measured by the number of cubic centimeters of normal acid that are consumed for neutralizing the same, which may be represented by x. Similarly, y c.c. of standard solution are required to neutralise the sulphide Na_2S; z c.c. are required to neutralize the carbonate Na_2CO_3; and w c.c. are required to neutralize the sulphite Na_2SO_3. This being

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understood, the following are the various steps to be followed in performing the analysis:

I. Take 5 c.c. of the liquor, dilute it in cold water, and titrate with N/1 hydrochloric acid HCl solution, using phenolphthalein as an indicator. The reaction is ended as soon as the color turns from red to colorless. Note the number of cubic centimeters of acid consumed, which denote by a; then a c.c. of normal HCl solution have neutralized all the NaOH, $\frac{1}{2}$ of the Na_2S, and $\frac{1}{2}$ of the Na_2CO_3 contained in 5 c.c. of the liquor. The reaction is expressed by the following:

$$NaOH + Na_2S + Na_2CO_3 + HCl \rightarrow NaCl + NaSH + NaHCO_3 + H_2O$$

A true equation cannot be written, because the proportions of the reacting substances cannot be definitely stated. Here a c.c. of HCl was used, to neutralize all the NaOH, $\frac{1}{2}$ the Na_2S, and $\frac{1}{2}$ the Na_2CO_3; and x c.c. was consumed by the hydrate, $y/2$ c.c. by the sulphide, and $z/2$ c.c. by the carbonate; thus,

$$x + \frac{y}{2} + \frac{z}{2} = a,$$

or,
$$2x + y + z = 2a. \qquad (1)$$

II. The titration is continued, using the same sample and without refilling the burette, but methyl orange is now used as an indicator, to determine the carbonate. A turn of the color of the solution from yellow to pink indicates the end of the reaction. The total number of cubic centimeters of acid used in this test and the preceding ($= b$) measures the concentration of the hydrate, sulphide, and carbonate—all of which are fully neutralized—and half the sulphite is also neutralized, in accordance with the equation

$$NaOH + Na_2S + Na_2CO_3 + Na_2SO_3 + 6HCl = 6NaCl + NaHSO_3 + H_2S + CO_2 + 2H_2O$$

Hence,
$$x + y + z + \frac{w}{2} = b,$$

or,
$$2x + 2y + 2z + w = 2b. \qquad (2)$$

III. Dilute 5 c.c. of the liquor to 50 c.c. in a measuring flask; 1 c.c. of this solution then contains $\frac{5}{50} = \frac{1}{10}$ c.c. of the liquor. Take 5 c.c. of this solution, mix with 200 c.c. of cold water, and acidify with a slight excess of acetic acid, and then titrate with

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N/10 iodine solution. Since the solution titrated is $\frac{1}{10}$ concentration and the iodine solution is $\frac{1}{10}$ normal, the proportions obtained by titration will be the same as though the original liquor had been titrated with a normal iodine solution. During the reaction, the sulphide is changed to an iodide and the sulphite is oxidized to a sulphate, and the completion of the reaction is indicated by the color turning to blue, due to the action of the slightest excess of iodine on the starch indicator, a few c.c. of which is added during titration. The reaction is in accordance with the equation

$$H_2O + Na_2S + Na_2SO_3 + 2I_2 = 2NaI + Na_2SO_4 + S + 2HI$$

Let c = the number of c.c. of the N/10 iodine solution that were used; then

$$y + w = c. \qquad (3)$$

IV. Bring 5 c.c. of the liquor into a 50 c.c. measuring flask, mix with 10 c.c. of alkaline zinc acetate solution, and dilute the mixture to the mark. A precipitation of the zinc sulphide is obtained, which eliminates the Na_2S, and the sulphite is left unchanged. The solution is filtered through a dry filter into a dry beaker, 5 c.c. of the filtrate (the solution that has passed through the filter) is mixed with 200 c.c. of cold water, and acetic acid is added. This solution is titrated with N/10 iodine solution, using starch as an indicator. When the color turns blue, the oxidation of the sulphite (the reaction) is completed, in accordance with the equation

$$H_2O + Na_2SO_3 + I_2 = Na_2SO_4 + 2HI$$

Letting d = the number of c.c. of iodine solution used,

$$d = w. \qquad (4)$$

The content of Na_2SO_3 is usually so small that it suffices to perform this analysis a couple of times a week and disregard it in every-day analysis.

Equations (1)–(4), just derived, are simultaneous; from them, the values of x, y, z, and w may be found in terms of a, b, c, and d, which are known quantities, and the percentages or grams per liter (g./l.) may then be readily calculated. Thus,

$$\begin{aligned} 2x + y + z &= 2a. \qquad (1)\\ 2x + 2y + 2z + w &= 2b. \qquad (2)\\ y + w &= c. \qquad (3)\\ w &= d. \qquad (4) \end{aligned}$$

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Equation (4) gives the value of w directly; substituting it in (3),

$$y + d = c;$$

from which,

$$y = c - d. \qquad (5)$$

Subtracting (1) from (2),

$$y + w + z = 2b - 2a = 2(b - a);$$

or,

$$z = 2(b - a) - c, \qquad (6)$$

since by (3), $y + w = c$.

Substituting in (1) the values of y and z,

$$2x + c - d + 2b - 2a - c = 2a;$$

from which,

$$x = 2a - b + \frac{d}{2}. \qquad (7)$$

Knowing the values of x, y, z, and w, the number of grams per liter of the substances represented by these quantities is found as follows:

The amount of sodium hydrate NaOH, the molecular weight of which is 40, is represented by x, the value of which is given by equation (7). 1 liter of normal NaOH solution therefore contains 40 g. of NaOH, and 1 c.c. of normal HCl neutralizes $40 \div 1000 = .040$ g. of NaOH. The amount of solution in sample was 5 c.c.; hence, the number of c.c. of acid that neutralizes 5 c.c. of solution containing NaOH is x c.c. Consequently, 5 c.c. of solution contains $.040x$ g. of NaOH; 1 l. of solution contains $\frac{.040}{5}x \times 1000 = 8x$ g.; and the number of grams of NaOH per liter in the original solution is

$$8x \text{ g./l.} = 8\left(2a - b + \frac{d}{2}\right) \text{ g./l.} \qquad (8)$$

If the sulphite be neglected, $d = 0$, and the formula becomes

$$\text{Grams NaOH per liter} = 8(2a - b) \text{ g./l.} \qquad (9)$$

The amount of sodium sulphide, Na_2S, which has a molecular weight of 78, is represented by y, the value of which is given in equation (5). 1 c.c. of N/1 acid neutralizes $\frac{78}{2} \div 1000 = .039$ g. of Na_2S. Since the sample of Na_2S solution that was titrated contained 5 c.c. and a normal acid was used, the number of grams of Na_2S per liter in the original solution was $\frac{.039}{5}y \times 1000 = 7.8y$; hence, from equation (5),

$$\text{Grams } Na_2S \text{ per liter} = 7.8(c - d) \text{ g./l.} \qquad (10)$$

Or, disregarding the sulphite,

$$\text{Grams } Na_2S \text{ per liter} = 7.8\,c \text{ g./l.} \qquad (11)$$

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Although decinormal solutions of iodine were used in titrating for Na_2S ($= y$) and Na_2SO_3 ($= w$), the solution titrated was only one-tenth the strength of the original solution; hence, the proportions may be found (as previously stated) by considering both to be normal. The molecular weight of Na_2CO_3 is 106; consequently, reasoning as above, the number of grams of Na_2CO_3 per liter is $10.6z$. Or, substituting the value of z from equation (6),

$$\text{Grams } Na_2CO_3 \text{ per liter} = 10.6[2(b - a) - c] \text{ g./l.} \quad (12)$$

The molecular weight of the sodium sulphite ($= w$) is 126; consequently reasoning as above, the number of grams of Na_2SO_3 per liter is $12.6w$. Or, substituting the value of w from equation (4),

$$\text{Grams } Na_2SO_3 \text{ per liter} = 12.6d \text{ g./l.} \quad (13)$$

When finding the molecular weights of the sulphide and sulphite, the atomic weight of sulphur was taken as 32, which is close enough for the present purpose.

9. Active Alkali and Per Cent of Causticity.—The method of analysis just described may be used to the same advantage in connection with white liquor as with green liquor. In the case of white liquor, there are two items of special importance, and which should always be specified when the results are expressed; these are the *active alkali*, which may be represented by K, and the *percentage of causticized soda*, otherwise called the *per cent of causticity*, which may be represented by C. The active alkali is the sum of the hydrate and the sulphide, and is given in terms of either sodium oxide or of sodium hydrate, in accordance with the following formulas, in which the various letters denote the same quantities as in Art. **8.**

$$\text{As NaOH, } K = 8(x + y) = 8(2a - b + c - \frac{d}{2}) \text{ g./l.} \quad (1)$$

$$\text{As } Na_2O, K = 6.2(x + y) = 6.2(2a - b + c - \frac{d}{2}) \text{ g./l.} \quad (2)$$

Or, if the determination of the sulphite be omitted, $d = 0$, and

$$\text{As NaOH, } K = 8(2a - b + c) \text{ g./l.} \quad (3)$$

$$\text{As } Na_2O, K = 6.2(2a - b + c) \text{ g./l.} \quad (4)$$

Formula (1) is obtained by substituting the values of x and y as given in equations (5) and (7) of Art. **8.** The constant 6.2 in formula (2) is one-tenth the molecular weight of Na_2O, or $\frac{62}{10} = 6.2$.

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The per cent of causticity (C) is the ratio of the sodium hydrate to the sum of the sodium hydrate and sodium carbonate, all expressed in terms of Na_2O, and also expressed as a per cent. Omitting the sulphite, $d = 0$, and

$$C = \frac{6.2x}{6.2(x + z)} \times 100 = \frac{100x}{x + z}$$

Substituting the values of x and z from equations (6) and (7),

$$C = \frac{2a - b}{b - c} \times 100 \qquad (5)$$

10. Analyzing White and Green Liquors.—The method just given for analyzing liquors calls for two different standard solutions, a normal (N/1) HCl solution, and a decinormal (N/10) iodine solution. It may, therefore, not be advisable to use this method in the mill, in the liquor room, or in the digester room. In the digester room especially, where a mistake may prove fatal to the success of the cook, it is better to employ a more direct method, in which only one reading of the burette is necessary. By this method, called the **barium chloride method,** the causticity of the liquor and its content of active alkali can be determined by using only one standard solution.

11. The Barium Chloride Method.—For the control of the liquor in the liquor room, a sample of the liquor is taken out after the minimum quantity of lime has been added, or, as some mills are operated ,when causticizing is thought to be complete. The analysis then proceeds as follows:

I. Take 5 c.c. of the clear liquor and titrate it with N/1 HCl, using methyl orange as an indicator. The change in color from yellow to pink occurs when all the NaOH, all the Na_2S, and all the Na_2CO_3 is neutralized. The reaction is expressed by the equation

$$NaOH + Na_2S + Na_2CO_3 + 5HCl = 5NaCl + H_2S + CO_2 + 2H_2O$$

Represent the amount of acid used by s c.c.

II. Bring 25 c.c. of clear white liquor into a 250 c.c. measuring flask and mix with 50 c.c. of 10% barium chloride ($BaCl_2$ cryst.) solution; the mixture is then diluted to the mark, well mixed, and allowed to settle. The white precipitate thus obtained is barium carbonate $BaCO_3$, and the sodium carbonate is thus eliminated, in accordance with the equation

$$Na_2CO_3 + BaCl_2 = 2NaCl + BaCO_3$$

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From the clear solution of the above mixture, 50 c.c. is carefully withdrawn, taking pains to avoid any of the precipitate. The sample thus obtained is titrated twice with N/1 HCl solution, first using phenolphthalein as an indicator, and then using methyl orange as an indicator. The first reaction ends when the original pink color of the phenolphthalein turns to colorless, and as a result of this reaction, which is expressed by the following equation,

$$NaOH + Na_2S + 2HCl = 2NaCl + NaHS + H_2O$$

all the NaOH and half the Na_2S is neutralized. Represent the amount of acid used by t c.c. Continue the titration (using methyl orange as indicator) until the color turns from yellow to pink; this reaction neutralizes the NaHS, in accordance with the equation

$$NaHS + HCl = NaCl + H_2S$$

Represent the amount of acid used in this complete titration (both parts) by u c.c.

These results may be summarized thus:

All NaOH + all Na_2S + all Na_2CO_3 neutralized by s c.c. of HCl
All NaOH + half (1/2) Na_2S neutralized by t c.c. of HCl
All NaOH + all Na_2S neutralized by u c.c. of HCl

From these results, are obtained the following formulas, which express the determinations of carbonate, hydrate, and sulphide:

$$Na_2CO_3 \left\{ \begin{array}{l} = 6.2(s-u) \text{ g./l. as } Na_2O \\ = 10.6(s-u) \text{ g./l. as } Na_2CO_3 \end{array} \right\} \quad (1)$$

$$NaOH \left\{ \begin{array}{l} = 6.2(2t-u) \text{ g./l. as } Na_2O \\ = 8(2t-u) \text{ g./l. as NaOH} \end{array} \right\} \quad (2)$$

$$Na_2S \left\{ \begin{array}{l} = 2(u-t) \times 6.2 \text{ g./l. as } Na_2O \\ = 2(u-t) \times 7.8 \text{ g./l. as } Na_2S \end{array} \right\} \quad (3)$$

As before, representing the per cent of causticity by C,

$$C = \frac{2t-u}{s-2(u-t)} \times 100 \quad (4)$$

The student should compare this with determination of causticity of carbonate liquors in section on *Soda Pulp*.

The last formula gives the result that is of particular interest to the liquor maker. If the result as found is not satisfactory, the liquor maker should refer to a table (computed for the purpose) and ascertain how much more lime must be added to get the liquor to the proper causticity. The computation of this table

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is a matter for the chemist, and the table will usually be different for each mill.

In the digester room, where only the total active alkali is of interest, only the last part of the above analysis is made. Thus, 25 c.c. of the liquor is precipitated with 50 c.c. of 10% barium chloride solution and diluted to 250 c.c. in a measuring flask. Then 50 c.c. of the clear solution is withdrawn and titrated with N/1 HCl solution, using methyl orange as an indicator. The change of color from yellow to pink marks the end of the reaction, in accordance with the expression

$$NaOH + Na_2S + HCl \rightarrow NaCl + H_2S + H_2O$$

which shows that all the NaOH and all the Na_2S has been neutralized. The amount of acid used will be the same as in the total for II, above, *i.e.*, u c.c. Representing the total active alkali by K, as before,

$$K \left\{ \begin{array}{l} = 6.2u \text{ g./l. as } Na_2O \\ = 8u \text{ g./l. as NaOH} \end{array} \right\} \qquad (5)$$

Knowing the number of c.c. of acid used in making the foregoing analysis, a table (prepared for the purpose by the chemist) may be consulted for the purpose of determining directly how many inches to use out of the measuring tank.

12. From the results of analyses of white liquor carried out by this method, a table or chart can be prepared that will show the amount of liquor of any strength necessary for digester charge that requires a certain amount of alkali.

In the formula,

$$h = 24 \times \frac{1}{A} \times \frac{1}{n_3} \times Q = \frac{24Q}{An_3}, \qquad (1)$$

Q = number of pounds of active alkali (given as NaOH) for a digester charge

A = area of measuring tank, in square feet;

n_3 = number of c.c. of $N/1$ acid neutralized by the active alkali in the liquor by the barium chloride method;

h = number of inches to be measured from the tank.

For any given size of tank, $\frac{24}{A} = c$, a constant, and

$$h = \frac{cQ}{n_3} \qquad (2)$$

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When preparing a table from this formula, n_3 is first kept constant and Q is varied (say at 50-lb. intervals) between the limits necessary to cover the digester sizes and cooking conditions. Then Q is kept constant, and values for n_3 are varied between proper (desired) limits. In this way, the value of h is obtained for any desired amount of active alkali and for any probable strength of white liquor. The actual weight of alkali must, of course, be determined for each digester, kind of wood, and quality of product.

13. Lime Sludge Analysis for Content of Sodium Salts.—The losses of chemicals in washing the lime sludge in the liquor room may be considerable; they are often times unduly large, because of poor settling qualities of the lime, or because proper care is not given to the washing by the man who operates the liquor room. Therefore, it is necessary to control the result of the washing operations from time to time. It may also happen that chemicals are wasted, because of improper agitation of the sludge in the settling tank. If part of the sludge in the tank is never stirred up by the agitator, a sample of sludge taken as directed below may show only traces of alkali, while the losses are still quite large; this should receive special attention when the losses of chemicals in the sludge are investigated.

When the sludge in a tank is fully washed, the amount of sludge is measured. The contents of the tank is then carefully agitated, and a good sized sample is taken out. If the settlings are very solid, it is advisable to mix in a little water before taking the volume of the sludge and the sample. The sample thus obtained is thoroughly stirred and, while still agitating, a test sample of 50 c.c. is withdrawn. The pipette used for this purpose must have an especially large discharge opening, to avoid having it plugged up with sludge. It is emptied into a porcelain dish, the inside is washed out with hot water, and 10 c.c. of a 10% solution of ammonium carbonate, $(NH_4)_2CO_3$, is then added, after which, the sample is evaporated to dryness on a water bath. The ammonium salts are then driven off, by slightly heating the dish over a Bunsen burner, and the residue is washed out onto a filter, where the washing is continued until no coloration is shown with phenolphthalein. The filtrate is then titrated with N/10 sulphuric acid H_2SO_4 solution, using methyl orange as an indicator. Note that 1 c.c. of acid corresponds to .004 g. of NaOH or to .0031 g. of Na_2O.

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To find the total content of sodium salts in the sludge, the sample thus tested for alkali is slightly acidified with hydrochloric acid, and is then precipitated with $BaCl_2$ in a boiling solution. The precipitate of $BaSO_4$ is taken on a filter and carefully washed, after which, the filter is burned wet in a platinum crucible and heated to white heat to constant weight. The weight thus obtained, less the weight of the crucible, is multiplied by .609 (see Art. 3); the product is the total content of the sodium salts in the sample, expressed as Na_2SO_4. Knowing the volume of the sludge in the tank, the size of the sample used for analysis, and the content of Na_2SO_4 in the salt cake, the actual loss of chemicals in the sludge, figured as commercial salt cake, is readily estimated.

14. Black Liquor Analysis.—To determine the total content of the sodium salts in the black liquor, 10 c.c. of liquor is diluted with water in a beaker and brought to boiling. A 50% solution of sulphuric acid is then added, drop by drop, until no further precipitation takes place and the solution is slightly acid. The organic substances in the black liquor, which are precipitated by the acid, will form a ball-shaped mass in the boiling-hot solution and are taken on a filter, where the precipitate is carefully washed with hot water. The filtrate, which contains the sodium salts (now all in the form of sodium sulphate) and the excess of sulphuric acid, is first evaporated to dryness on a water bath in a platinum dish; then the remaining water and the sulphuric acid are driven off by cautiously heating the platinum dish to dull red heat. The sodium sulphate is then weighed immediately; or, the salt residue is dissolved in water that has been slightly acidified with hydrochloric acid, and is precipitated with $BaCl_2$ in hot solution, and the sodium sulphate is weighed as $BaSO_4$. The weight of Na_2SO_4 (mol. wt. = 142) multiplied by .437 gives the content of sodium compounds in the sample as Na_2O (mol. wt. = 62), since $\frac{62}{142} = .437$. The weight of $BaSO_4$ (mol. wt. = 233.5) multiplied by .609 is the sodium as Na_2SO_4, since $\frac{142}{233.5} = .609$. Or, the $BaSO_4$ multiplied by .266 gives the weight of the sodium in the sample as Na_2O, since $\frac{62}{233.5} = .266$.

15. If the content of the sodium compounds in the black liquor at a certain specific gravity and temperature has once been determined and given either as Na_2O or as Na_2SO_4, the

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concentration of sodium salts in black liquor of any density at the same temperature can be calculated by the formula

$$Q_1 = Q \frac{d_1 - 1}{d - 1} \qquad (1)$$

in which Q = the content of sodium salts given as Na_2O (sometimes including Na_2SO_4) in grams per liter (g./l.) of the solution, the specific gravity of which is known and = d. Q_1 is the concentration of sodium salts, expressed as the same compound in the desired solution, the specific gravity of which is represented by d_1.

If it be desired to use American degrees Baumé instead of the specific gravity,

$$d = \frac{145}{145 - \text{Be.}} \qquad (2)$$

in which formula, Be. = number of degrees Baumé.

16. To determine the concentration of free caustic soda in the black liquor, a sample of 5 c.c. of liquor is mixed with 50 c.c. of 10% barium chloride solution ($BaCl_2$ cryst.) and is titrated with N/10 H_2SO_4, using phenolphthalein as an indicator. The color of the solution is made brighter through the precipitation of barium sulphate, and the turn of color to red can easily be observed. The number of c.c. of acid required for the reaction (= n c.c.) multiplied by .8 gives the content of free caustic soda in grams per liter (g./l.); thus,

$$\text{Grams NaOH per liter} = 0.8n \text{ g./l.}$$

Because of the presence of sodium sulphide in the black liquor, the result obtained in the manner just described is not quite exact; but, since the concentration of sulphide in the black liquor at the end of the cooking process is generally low, the error can be neglected in practice.

17. For determining the total alkali content of the black liquor, 5 c.c. of the liquor is diluted to 50 c.c. in a measuring flask. To 5 c.c. of the solution thus obtained, add 10 c.c. of N/10 H_2SO_4 solution and rapidly bring the mixture to boiling. The organic substances that are precipitated by the acid will form into a ball-shaped mass, and the solution containing them will be of a slightly yellow color. The excess of acid in this solution is determined by titration with N/10 barium hydrate $Ba(OH)_2$ solution, using phenolphthalein as an indicator. The amount of

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this solution that is used to neutralize the acid is denoted by m c.c. Then

$$8(10 - m) = \text{total alkali as NaOH} \quad (1)$$
$$6.2(10 - m) = \text{total alkali as } Na_2O \quad (2)$$

All analyses here described should be made with solutions of as nearly the same temperature as is possible, so that the results obtained may be compared with each other directly, without reducing them to the same temperature.

SUPPLEMENTARY TEST METHODS

GREEN LIQUOR ANALYSIS

NOTE.—In mill practice, it is often desired to express the results obtained from burette readings as pounds of Na_2O per cubic foot of liquor, to do this, in fact, directly from the burette readings. The following test methods may then be employed. It may be remarked that these methods are given here as a help to the mill chemist, and space does not permit of a discussion or explanations of the principles of chemistry involved.

18. Procedure.—A sample of the green liquor from the dissolving tanks is passed through a filter; the clear filtrate is then analyzed as follows for:

(*a*) $NaOH + Na_2S + Na_2CO_3 + \frac{1}{2}Na_2SO_3$, expressed as Na_2O. 2 c.c. of liquor is diluted with 50 c.c. of water, and is titrated with 0.5165N[1] hydrochloric acid, using methyl orange as an indicator. The number of c.c. of acid used, divided by 2, expresses the sum of the above mentioned components as Na_2O in pounds per cubic foot.

EXAMPLE.—10.45 c.c. of 0.5165N HCl ÷ 2 = 5.23 lb. of Na_2O per cu. ft.

(*b*) Na_2S, expressed as Na_2O.

2 c.c. of the same liquor (clear filtrate) is brought undiluted into a porcelain dish, and is titrated with 0.5165N ammoniacal silver nitrate solution. The silver nitrate is added slowly, continuously stirring with a glass rod. When a new drop does not form any more black silver sulphide, the end point is reached. The number of c.c. of 0.5165N solution consumed, divided by 2, gives the concentration of Na_2S, expressed as Na_2O, in pounds per cubic foot.

[1] To obtain 0.5165N solution, take 1000 c.c. of N/1 solution and add 936 c.c. of distilled water. The total volume is then 1936 c.c., and 1936: 1000 = N/1: xN; from which, xN = 1000 ÷ 1936 = 0.5165N.

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EXAMPLE.—3.78 c.c. of 0.5165N amm. silver nitrate ÷ 2 = 1.89 lb. Na_2S, expressed as Na_2O, per cu. ft.

(*c*) $Na_2S + Na_2S_2O_3 + Na_2SO_3$, expressed as Na_2O.

20 c.c. of green liquor is diluted with 50 c.c. of water, acidified with acetic acid, and an excess of N/10 iodine solution is added. The excess of iodine over that required by the liquor is determined by titration with N/10 sodium thiosulphate. When the solution is slightly yellow from iodine, a drop of starch is added, which colors the solution blue. The titration with thiosulphate is then continued until the blue color disappears. Subtract the number of c.c. of thiosulphate used from the number of c.c. of iodine solution used, and divide the remainder by 10.33 or multiply it by $\frac{3}{31}$; the quotient (or product) expresses the total of the above components as Na_2O, in pounds per cubic foot.

EXAMPLE.— Used 31.00 c.c. N/10 iodine solution
Used 10.32 c.c. N/10 thiosulphate
Liquor consumed 20.68 c.c. N/10 solution

Then, $\frac{20.68}{10.33} = 20.68 \times \frac{3}{31} = 2.00$ lb. Na_2O per cu. ft.

(*d*) $NaOH + Na_2S$, expressed as Na_2O.

20 c.c. of green liquor is titrated with 50 c.c. of 15% barium chloride solution, which precipitates all but the hydrate and sulphide of sodium. This is then diluted to 250 c.c. and left to settle. 25 c.c. of the clear solution is withdrawn and titrated, using methyl orange as an indicator. The number of c.c. of 0.5165N acid consumed, divided by 2, gives the concentration of $NaOH + Na_2S$ as Na_2O, in pounds per cubic foot.

EXAMPLE.—5.40 c.c. of 0.5165N HCl ÷ 2 = 2.70 lb. $NaOH + Na_2S$, expressed as Na_2O, per cu. ft. of liquor.

(*e*) $Na_2S + Na_2S_2O_3$, expressed as Na_2O.

20 c.c. of green liquor is treated with 50 c.c. of 15% $BaCl_2$ solution in a 250 c.c. measuring flask, and is made up to the mark; the contents, after being well shaken, are left to clear. Of the clear solution, 25 c.c. is withdrawn and mixed with 50 c.c. of water. After a slight excess of acetic acid has been added, the sample is titrated with N/10 iodine solution, added in excess. The excess of iodine is determined by re-titration with N/10 thiosulphate, using starch as an indicator.

EXAMPLE.— Used 21.50 c.c. N/10 iodine solution
Used 1.86 c.c. N/10 thiosulphate
Consumed 19.64 c.c. N/10 iodine solution

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Then, $\frac{19.64}{10.33} = 19.64 \times \frac{3}{31} = 1.90$ lb. $Na_2S + Na_2S_2O_3$, expressed as Na_2O, per cu. ft. of liquor.

(*f*) Na_2SO_4, expressed as Na_2O.

10 c.c. of green liquor is diluted with 50 c.c. of water; the solution is carefully acidified with a slight excess of hydrochloric acid, brought to boiling, and is precipitated with $BaCl_2$. The precipitate is left on the water bath for a few hours, and is then filtered. When the precipitate is washed clear, filter, and all is brought into a platinum crucible, burned, and heated, at white heat, to constant weight. The number of grams of barium sulphate (the precipitate obtained above) multiplied by 3.8 (3.799 more exactly) gives the number of pounds of Na_2SO_4 per cubic foot; or, if multiplied by 1.66 (1.659 more exactly), it gives the number of pounds of Na_2SO_4, expressed as Na_2O, per cubic foot.

EXAMPLE.—0.2634 g. $BaSO_4 \times 3.8 = 1.00$ lb. Na_2SO_4 per cu. ft.; or 0.2634 g. $BaSO_4 \times 1.66 = 0.44$ lb. Na_2SO_4, expressed as Na_2O, per cu. ft.

19. Calculation of Results.—Using the results obtained in Art. **18**,

(1) $Na_2CO_3 = (a) - (d) - \frac{(c) - (e)}{2} = 5.23 - 2.70 - \frac{2.00 - 1.90}{2} = 2.48$ lb. per cu. ft.

(2) $NaOH = (d) - (b) = 2.70 - 1.89 = 0.81$ lb. per cu. ft.

(3) $Na_2S = (b) = 1.89$ lb. per cu. ft.

(4) $Na_2SO_3 = (c) - (e) = 2.00 - 1.90 = 0.10$ lb. per cu ft.

(5) $Na_2S_2O_3 = (e) - (b) = 1.90 - 1.89 = 0.01$ lb. per cu. ft.

(6) $Na_2SO_4 = (f) = 0.44$ lb. per cu. ft.

SHORT METHOD FOR TESTING SULPHATE DIGESTER LIQUOR

20. Procedure.—The substances to be determined are the hydrate, sulphide, and carbonate of sodium in solution, expressed as pounds per cubic foot of Na_2O.

(*A*) $NaOH + \frac{1}{2}\ Na_2S + \frac{1}{2}\ Na_2CO_3$, expressed as Na_2O.

1 c.c. of digester liquor is run into a cup, and 50 c.c. of water is added. This is titrated with 0.5165N HCl, using phenolphthalein as an indicator. The number of c.c. of acid used expresses

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the amount of NaOH plus half the sulphide and half the carbonate.

(*B*) $\frac{1}{2}$ $Na_2S + \frac{1}{2}$ Na_2CO_3, expressed as Na_2O.

After the phenolphthalein end point is reached in (*A*), methyl orange is added to the same sample, and the titration is finished with 0.5156N HCl. The additional number of c.c. of acid thus used represents the amount required to neutralize the remaining half of the sulphide and carbonate.

(*C*) Na_2S, expressed as Na_2O.

1 c.c. of digester liquor is run into a cup and, without addition of water, is titrated with 0.5165N ammoniacal silver nitrate solution until no black precipitate of silver sulphide is formed. The titration is preferably done in a porcelain dish, and the silver nitrate solution should be run in drop by drop, so the effect of one drop may be noted before another drop is added.

21. Calculation of Results.—Using the results obtained in Art. **20,**

5.15 c.c. = HCl burette reading at methyl-orange end point (*B*).
4.30 c.c. = HCl burette reading at phenolphthalein end point (*A*).
0.00 c.c. = HCl burette reading at start (*A*)
1.40 c.c. = $AgNO_3$ burette reading at end point (*C*)
0.00 c.c. = AgNO burette reading at start (*C*)

(*A*) 4.30 c.c. = 4.30 lb. per cu. ft. of NaOH + $\frac{1}{2}$ Na_2S + $\frac{1}{2}Na_2CO_3$.

(*B*) 5.15 − 4.30 = 0.85 c.c. = 0.85 lb. per cu. ft. of $\frac{1}{2}Na_2S + \frac{1}{2}$ Na_2CO_3; 0.85 × 2 = 1.70 c.c. = 1.70 lb. per cu. ft. of $Na_2S + Na_2CO_3$; and 1.70 − 1.40 = 0.30 c.c. = 0.30 lb. per cu. ft. of Na_2CO_3 as Na_2O.

(*C*) 1.40 c.c. = 1.40 lb. per cu. ft. of Na_2S as Na_2O. 4.30 − 0.85 = 3.45 c.c. = 3.45 lb. per cu. ft. of NaOH as Na_2O.

QUICK METHOD FOR DETERMINATION OF WHITE LIQUOR

22. Procedure.—The following relates to the determination of the sulphate cooking liquor.

(*A*) For a total alkali, take 1 c.c. of white liquor and titrate with 0.5165 HCl, using methyl orange as an indicator.

(*B*) Take 10 c.c. of white liquor, and place in a 250 c.c. flask; precipitate with 15% barium chloride solution, dilute to the

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mark, shake well, and allow precipitate to settle. Withdraw 25 c.c. of the clear liquor and titrate, using phenolphthalein as an indicator for first end point; then continue titration, using methyl orange as an indicator.

EXAMPLES.—(*A*) 6.40 c.c. = $NaOH + Na_2S + Na_2CO_3$.

(*B*) 5.70 c.c. = end point with methyl orange for all $NaOH + Na_2S$;
4.60 c.c. = end point with phenolphthalein for $NaOH + \frac{1}{2} Na_2S$.
$(5.70-4.60) \times 2 = 1.10 \times 2 = 2.20$ c.c. = 2.20 lb. per cu. ft. of Na_2S as Na_2O.
$4.60 - 1.10 = 3.50$ c.c = 3.50 lb. per cu. ft. of NaOH as Na_2O.
$6.40 - 5.70 = 0.70$ c.c. = 0.70 lb. per cu. ft. of Na_2CO_3 as Na_2O.

RECLAMATION OF BY-PRODUCTS

23. Three By-Products of the Sulphate Process.—In the process of regenerating the alkali that is contained in the black liquor, 50% (more or less) of the dry weight of the wood that is carried in this liquor has to be removed, and the general practice, at the present time, is to burn the organic substances. The immense amount of material at hand, and the means it supplies for the manufacturing of useful and valuable organic products, has, of course, been an inducement leading research chemists to seek a practical and more profitable method of recovery. Acetone, wood alcohol, light and heavy motor oils, and lubricants, may all be obtained through destructive distillation of the black liquor, but the methods so far suggested have not proved satisfactory. For this reason, only a few products that can easily be isolated are reclaimed, they are sulphate turpentine, sulphate wood alcohol, and liquid rosin.

24. Turpentine.—The turpentine is already at hand in some wood as such, when the wood is charged into the digester. During the early part of the cook, when the digester is relieved, to exhaust the air and maintain circulation, most of the turpentine is carried over in the escaping steam. Later in the process, when the cook is ready and the digester is relieved down to blowing pressure, the agitation caused by the rushing steam drives off another part of the turpentine. If the relief gases are condensed and the condensate left to stand, the turpentine oil will separate from the water, and may be drawn off. The crude product thus obtained contains about 50% turpentine, and it must be purified by fractional distillation. A careful distillation, carried through

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in a column apparatus, will result in a colorless and scentless product that compares very favorably with turpentine otherwise obtained. In some instances, it has been found necessary to wash the turpentine, after the distillation, with a weak solution of sulphuric acid, and follow this with a wash of sodium hydrate solution. It has also been found to be advantageous to add a little lead acetate solution before the final distillation, to remove the last traces of sulphur. In case of discoloration, the turpentine may be stored for some time in glass containers exposed to sunlight.

Among other products that may be isolated from the crude turpentine is methyl sulphide, which, according to Bergstrom, makes up about 30% of the total oil; this may become valuable, if it can be used as a solvent for nitro-cellulose in place of ether. The crude turpentine oil also contains a small percentage of wood alcohol and methyl disulphide.

The actual quantity of crude turpentine oil obtained from the condensate will naturally vary quite extensively with the kind of wood used; it will likewise vary with the manner of cooking and of relieving the digester. The lower the blowing pressure of the digester the larger will be the return of turpentine per charge, with the same wood. Apparatus especially designed for separating the turpentine from the condensed steam and for its distillation, may be purchased in the market.

25. Wood Alcohol.—Wood alcohol (methyl hydrate), which is not to be found as such in the wood, is a product that results from the hydrolysis of the higher carbohydrates. The quantity of wood alcohol actually formed in the digester during the cook is estimated to be about 25 pounds per ton of pulp, in the case of a straight soda cook. By the sulphate process, the quantity will not be so large, since a portion of the methyl compounds are engaged by the sulphur; from 7 to 9 pounds of wood alcohol may be expected per ton of pulp, the quantity formed in the digester being about twice this amount.

The wood alcohol, like the turpentine, is to be found in the relief gases from the digester, and in the condensed fumes from evaporators also, particularly in the condensate from the second effect. The concentration of wood alcohol in both of these condensates is very small, and the first operation is undertaken with a view to obtaining a solution having a higher percentage of alcohol.

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The united condensate from the digester relief and from the second evaporator effect is continuously fed to the tower of the concentrating apparatus, over a perforated plate at the top in the lower compartment, which is filled with rock; it is then distributed over the whole section of the cylinder. Steam is introduced underneath the grate, and the rising steam meets the condensate as it runs down over the rocks, which afford a large evaporation area. As the vapors rise, they become richer and richer in their content of wood alcohol, which is more volatile than the water. The water flow through the coil in the top section is carefully adjusted, so as to obtain the highest possible concentration of alcohol in the vapors that leave the machine for the condenser; a temperature of between 170° and 180°F. will usually give the best results. The condensate from the condenser flows by gravity into a storage tank. The crude product obtained in this manner contains from 10% to 20% wood alcohol.

When a sufficient quantity of the crude alcohol is at hand, redistillation is undertaken in an apparatus similar in construction to the one previously described, but having a smaller capacity. It consists of a fairly large vessel, indirectly heated with a steam coil, in which the crude alcohol is charged. Above this vessel is placed a column filled with pebbles or small crushed stone. On top of the column is placed a cooler, and on top of that a condenser. When the vapors from the heating vessel strike the cooler in the top of the column, a part is condensed and runs back over the pebbles, where the condensate meets with fresh vapor from the bottom. The fraction with the lowest boiling point will thus accumulate at the top of the machine. The water in the cooler is regulated to maintain a temperature of 150°F. at the top of the column; in this manner, the vapor leaving the column will contain practically nothing but wood alcohol, which is condensed and collected in a tank.

Wood alcohol obtained by this process has a concentration of about 98%; it is perfectly clear and is practically free from discoloration and scent; it contains but a trace of acetone, and is a far purer product than that obtained from the distillation of wood.

26. Liquid Rosin.—When black liquor is left to stand for some time, a layer of soap is formed on top of the liquor; this soap has a yellow color, but turns black when exposed to the air. The soap

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comes from the constituents of the wood that are of a resinous or fatty nature, and is formed through saponification of these constituents. The soaps that are the result of this hydrolysis are carried partly in solution and partly in suspension in the black liquor. The concentration of the solution of soap becomes less the higher the concentration of the other sodium salts. If the black liquor is left at rest for some time, the part of the soap that is in suspension will float to the top, in very much the same way as cream comes to the top of milk. The concentration of the suspended soaps is higher in a more concentrated black liquor, and the separation of the soap from the liquor will be more complete accordingly; for this reason, the mills where this product is taken care of always carry a large stock of evaporated liquor. The storage tanks for this purpose are supplied with an overflow, an open spout at the top of the tank, through which the soap is run off into a special soap tank. Any black liquor that follows the soap into this tank is drawn off at the bottom.

27. The liquid rosin is obtained from the soap through precipitation with an inorganic acid. If the soap be let into a boiling solution of hydrochloric acid, a dark brown oil is obtained, which is viscous at ordinary temperatures. The reaction takes place according to the formula

$$NaR + HCl = HR + NaCl$$

in which R represents some organic radical.

The oil, which floats on top of the sodium chloride solution in a distinct layer, can easily be skimmed off. The acid value and iodine value of this oil or of the distillates that are obtained from the same through distillation in vacuo, indicate that the oil originates from the abietic and fatty acids in the wood. A gravel-like substance, which in time will separate from the oil and settle down to the bottom of the container, is derived from the lignins of the wood. According to Bergstrom, the sulphate liquid rosin consists of a mixture of fatty acids, principally palmitic acid and resin, with a small percentage of phytosterins. The composition of the liquid rosin, and the quantity obtained as well, varies greatly with different kinds of wood and with varying conditions of the same kind of wood. Thus, the percentage of the fatty acids will be considerably higher in liquid rosin obtained from wood cut in the summer time; and this will also be the case if only sap wood is used, as in mills utilizing

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sawmill refuse. A yield of 70–80 lb. of rosin per ton of pulp may be considered satisfactory.

28. In mill practice, the soap is treated with a solution of niter cake in preference to an acid, since the former is not so hard on the vessel in which the reaction occurs. The solution of niter cake is prepared in a special vessel, which is lined with lead and acid-proof brick. The water is heated with indirect steam, and niter cake is added until a solution is obtained that corresponds to 7–8 normal acid or to a density of about 40°Be. (hot). When this solution is ready, it is put into the vessel in which the liquid rosin is prepared. This vessel, which may be of wood or of copper-lined sheet iron, is cylindrical in shape; it is equipped with a coil for heating, and it has an outlet at the bottom for the resulting sodium sulphate solution and the liquid rosin. The vessel is filled nearly half full with the niter-cake solution, to which the soap is gradually added while the whole is kept boiling. During the course of the process, samples of the niter-cake solution are taken out at intervals and titrated with N/1 NaOH. Soap is added until the concentration of niter cake corresponds to an acid of about N/5 strength. The boiling is then continued for another half hour, to make certain that all the soap is precipitated; after which, the solution of sodium sulphate is drawn off, mixed into the black liquor, and the liquid rosin is put into barrels. In the bottom of the vessel, is a layer of precipitated sodium sulphate, which is used in the furnaces as salt cake. The liquid rosin obtained in this way should have an acid value of at least 160, and should contain but a trace of sodium sulphate.

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MANUFACTURE OF SULPHATE PULP

EXAMINATION QUESTIONS

(1) How does the liquor-room foreman know how much lime to add to a causticizing tank?

(2) What happens when green liquor is treated with lime? is the reaction complete?

(3) What are the principal steps in operating a digester?

(4) From the diagram shown in Fig. 8, tell how this cook was conducted.

(5) What effect does moisture in chips have in the operation of the digesters?

(6) Explain the operation of the diffuser.

(7) On what principle does the multiple-effect evaporator depend?

(8) Which do you think is the better and why, the direct-flow system or the counter-flow system, for a multiple-effect evaporator?

(9) What does the black liquor contain?

(10) How is sodium sulphide produced?

(11) What does black ash contain?

(12) What factors must be considered in the operation of a smelting furnace?

(13) Describe the operation of starting the furnace room.

(14) Mention some of the advantages of reclaiming chemicals.

(15) (*a*) Why is the lime sludge carefully washed? (*b*) What use is made of the wash water and of the washed sludge?

(16) Name four substances that might be recovered as by-products from a sulphate-pulp mill.

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SECTION 7

TREATMENT OF PULP

BY J. O. MASON

COARSE SCREENING

INTRODUCTION

1. Object of Pulp-Making Processes.—The details of the manufacture of mechanical and chemical pulps have been covered in the preceding Sections of this volume. The subsequent treatment of these pulps, from the point where the mechanical pulp is taken from the grinder pits and the chemical pulp leaves the blow pits, washers or diffusers to their delivery to the paper mill or cars, ready for shipment, together with all the intermediate processes, will be described in this Section.

The object of the pulp-making processes is to produce the largest quantity of a specified quality of pulp from a given unit of raw material. But it is inevitable, due to many causes, that all of the pulp produced is not of the required quality; the reason for this will appear as the reader progresses.

Mechanical pulp, hereafter frequently referred to as **groundwood,** as it comes from the grinder pit, is a mass of separated wood fibers of varying size, together with slivers of wood and slabs unground, the whole being mixed with a relatively small amount of water. **Chemical pulps** coming from the washing tanks contain knots and partially cooked chips, together with foreign matter and dirt, such as pieces of digester brick, cement, etc. In both cases, this coarse material and fiber must be separated from the first quality pulp with which they are mixed.

The diagram on next page shows the course of the stock through the pulp mill after its manufacture by cooking or grinding. Later, it will be explained that pulp in laps may be pressed and that chemical pulp may be dried by pressure and steam

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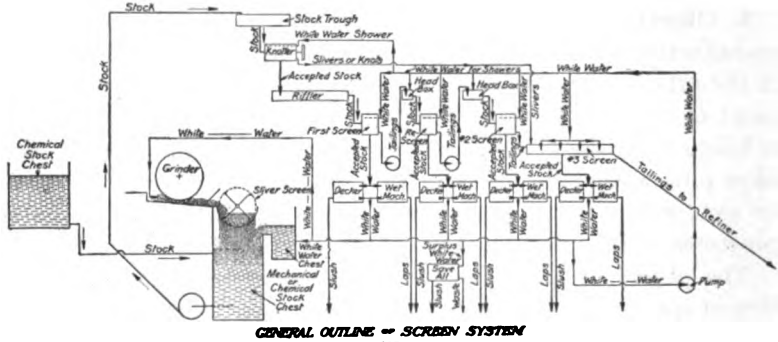
heat on special machines. Screens are selected in accordance with the character of the stock.

STORAGE OF PULP BEFORE SCREENING

2. Groundwood.—Groundwood is produced by what is called a *continuous process* of manufacture; that is, from the time the fibers are ground off the log until they are in a suitable form for use in the paper mill, there is no period of rest or inactivity—they pass from one stage to the next continuously. Therefore, it is not necessary to set aside any portion of the product in a reservoir or other container, from which to draw at a subsequent stage of the process.



GENERAL OUTLINE OF SCREEN SYSTEM FOR MECHANICAL OR CHEMICAL PULP

3. Chemical Pulp.—Chemical pulp, on the other hand, is produced by an *intermittent*, or *discontinuous, process*, due to the cooking of the batches. It is desirable, however, to make the succeeding events of the process continuous, for reasons that will be apparent as the details of the process are described.

Each *batch*, or digester charge, varies from two to four tons in the case of soda and sulphate pulps to ten to eighteen tons in the case of sulphite pulp. It is necessary for two reasons to have a storage tank to receive the batch as it is delivered from the blow pit:

First. When changing from a discontinuous to a continuous system, it is a necessity, in order to secure a continuous supply of stock, that a reserve be set up, thus providing for delays and inequalities in the cooking time. Delays in the screening system

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are also likely to occur, and if there were no reservoir, such delays might require the discharging of a batch of freshly cooked pulp into a blow pit containing washed stock, which would make the whole mass unfit for screening for several hours. *Second.* The rate of delivery from the blow pit or diffuser is usually much in excess of the amount that can be taken care of by the screening system, and the amount of water mixed with the stock varies from time to time, as the drainer or blow pit is being washed out. Since such conditions are not conductive to securing good results in the screening system, storage tanks having a capacity sufficient for at least one digester charge (sometimes two) are provided. These tanks may be of concrete, either lined or unlined, or of wood, or of any other material suitable for the kind of stock to be stored.

4. Consistency.—Throughout this Section, the term **consistency,** or **density,** will frequently be used; as applied to pulp, it means the per cent by weight of *air-dry* fiber in any combination of fiber and water. The term **bone-dry fiber** means fiber from which all water has been removed by heating; this condition is never obtained nor sought in the pulp mill. **Air-dry fiber** contains 10% moisture; that is, the amount of bone-dry fiber contained in any given weight of air-dry fiber is equal to the air-dry weight multiplied by .9 (1 − .10 = .90). Consequently, if A = weight or per cent (by weight) of air-dry fiber and B = weight or per cent of bone-dry fiber,

$$B = A \times .9 \qquad (1)$$
$$A = B \div .9 \qquad (2)$$

Let C = the consistency, expressed as per cent of air-dry fiber, W = the weight of any particular amount of stock, and A = the weight of air-dry fiber in that amount of stock; then,

$$C = \frac{A}{W} \times 100 \qquad (3)$$
$$A = \frac{WC}{100} \qquad (4)$$
$$W = \frac{A}{C} \times 100 \qquad (5)$$

EXAMPLE.—Suppose the consistency of a certain stock is 1.63% (air-dry); how many pounds of (*a*) air-dry fiber and (*b*) of bone-dry fiber are contained in 2800 gallons of stock, if one gallon weighs $8\frac{1}{3}(=\frac{10.0}{12})$ pounds?

NOTE—One U. S. gallon weighs $8\frac{1}{3}$ pounds but one Imperial (Canadian legal) gallon weighs 10 pounds. The U. S. gallon is used in this book.

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SOLUTION.—(*a*) Here $W = 2800 \times \frac{100}{12}$ and $C = 1.63$; hence, by formula (4),

$$A = \frac{2800 \times 100 \times 1.63}{12 \times 100} = 380\tfrac{1}{4}, \text{ say } 380 \text{ lb.} \quad \textit{Ans.}$$

(*b*) Applying formula (1),

$$B = 380 \times .9 = 342 \text{ lb.} \quad \textit{Ans.}$$

In examples of this kind, it is useless to calculate results correct to more than three significant figures.

5. The consistency of the stock in the storage tank varies considerably, depending upon the amount of water added to sluice it or pump it from the drainer. It is often between 2% and 4%, and the average practice possible under the conditions obtaining at each plant should be determined before designing the tank. The lower the consistency the larger the tank must be. Thus, if the consistency is 2%, each 100 lb. of air-dry fiber will occupy a space of approximately 80 cu. ft., since the weight of the stock will then be, using formula (5) of Art. **4**,

$$W = \frac{A}{C} \times 100 = \frac{100}{2} \times 100 = 5000 \text{ lb.}$$

Taking the weight of a cubic foot of the stock as 62.4 lb., the same as the weight of a cubic foot of water, which is close enough for all practical purposes, the number of cubic feet in 5000 lb. of stock is $5000 \div 62.4 = 80$ cu. ft., very nearly.

It may here be remarked that it is advisable to keep the stock agitated while it is being stored in the tank, in order that it may be of practically uniform consistency throughout. This may be effected by using a paddle somewhat like that employed in an ice-cream freezer.

MACHINES USED IN COARSE SCREENING

6. Necessity of Screening.—One of the leading processes employed in the treatment of pulp is the separation of the coarse fibers from the fine, or *majority*, fibers and the removal of dirt and foreign matter. This process separates the fibers into classes, according to size and length. The machine that accomplishes this separation is called a **screen,** and the process is called **screening.** For the purpose of obtaining greater efficiency in screening, the reasons for which will be considered later, the pulp is first

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passed through one or more sets of coarse screens and then, if desired, through a shallow tank called a *riffler*.

It is important to appreciate at the outset that water plays an important part in *all* the processes, from the moment that pulps are made until they are incorporated into the finished products. Water acts as a conveyor for the fibers, holding them in suspension as they are pumped from place to place while being sorted and treated. Finally, when no longer needed, the water is extracted in various ways.

7. The coarsest material in groundwood, consisting of thin slabs of unground wood and slivers of varying size, must be removed before any attempt is made to pump it, since this material will clog any type of pump. Accordingly, sufficient water is added to thin the mass, so it will flow freely. The consistency at this point is, approximately, from $\frac{3}{4}\%$ to $1\frac{1}{4}\%$, but uniformity in consistency is not so important here as at all subsequent stages, since the machines for coarse screening present the largest passages through which the stock must pass.

SCREENS FOR GROUNDWOOD

8. Slab Grating.—The machine shown in Fig. 1 is called a **slab grating.** The parts bearing numbers are designated as follows: 1, sprocket wheel for chain; 2, scraper; 3, chain; 4, bars; 5, stock canal; 6, platform.

This machine is an elementary device for taking slabs and very coarse material from groundwood pulp before it is pumped. The stock runs in a canal in the direction indicated by the arrow. A grating of iron bars, set on edge and spaced about 1 inch apart, is placed in the path of the current of stock; this grating is inclined, as shown in (*a*). The coarse material that fails to pass between the bars is carried up the incline by the scrapers 2 on the chain 3, and are deposited on the platform 6, from which they are removed. The width of the scraper is such that it extends over all the bars.

9. Sliver Screens.—All **sliver screens** consist of a screening element, contain some device for the removal of slivers, and provide means for keeping the holes or slots in the screening element clear. The screening element is usually a perforated steel plate, having circular holes from $\frac{3}{4}$ in. to $\frac{5}{32}$ in. in diameter, and may be mounted on a stationary, rotating, or oscillating

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frame. If the frame be stationary or oscillating, scrapers move over the surface of the plate and remove the slivers that are deposited by the stock as it passes through the holes in the plate. If the frame and screen plate rotate, the screen is so constructed that it discharges the slivers at one end of the rotating drum to which the screen is attached, and the flow of stock is always from the inside to outside. The slivers are freed from such fibers as cling to them by a shower of water, and are usually thrown away, while the larger slabs are returned to the grinders. The loss varies, depending upon the size of the holes in the screen plate, and may be from ½% to 1¼%. The consistency of the stock going to this screen is dependent upon the size of the perforations in the screen; that is, if the perforations are large, the stock will naturally have a greater consistency than if they are small. Evidently, the size of the perforations is a matter to be decided by the designer, who is largely governed by the requirements of the subsequent processes. If only one set of sliver screens are to be used, the perforations should be relatively fine; but, if two sets are provided, the first set should have relatively large perforations, while those in the second set should be fine.

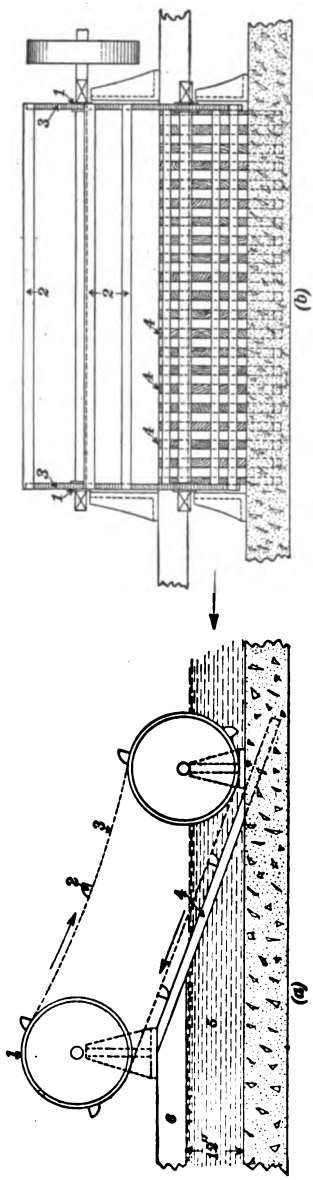

FIG. 1.

The matter may be summed up thus: the larger the perforations in the screen plate the thicker the stock *may be*, and the poorer the screening will be; conversely, the smaller the perforations the

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thinner the stock *must be*, and the better will be the results obtained from screening. It is obvious that the size of the perforations and the consistency of the stock affect the **capacity** (*quantity production*) of the screen.

10. Assume that the stock from the sliver screen has to be pumped to the screen room. If there is any considerable head to pump against, the quantity pumped is important. It would be possible to screen through a plate having $\frac{3}{4}$-inch or $\frac{5}{8}$-inch perforations at $1\frac{1}{4}\%$ consistency. Since $1\frac{1}{4}\% = .0125 = \frac{1}{80}$, it will require the pumping of $2000 \div \frac{1}{80} = 2000 \times 80 = 160{,}000$ lb. = 80 tons of liquid to secure 1 ton of *air-dry* pulp. Taking the weight of 1 gal. of stock as $8\frac{1}{3} = \frac{100}{12}$ lb., the number of gallons pumped for each ton of air-dry pulp is $160{,}000 \div \frac{100}{12} = 160{,}000 \times .12 = 19{,}200$ gal. The stock passing through the screen would contain many slivers, which would clog the screen plate of the main screens, thus curtailing their capacity and detracting from the efficiency of screening. On the other hand, if the perforations were $\frac{5}{32}$ inch to $\frac{3}{16}$ inch in diameter, the consistency would be about $\frac{1}{2}\%$ and the number of gallons of stock to be pumped for each ton of air-dry pulp would be, by formula (5) of Art. **4**, $\frac{2000}{.5} \times 100 \div \frac{100}{12} = 48{,}000$ gal. In the latter case, very few slivers would remain in the stock to affect adversely the main screens. Therefore, it may be found advisable to screen once at relatively high consistency, and then pump to a second set of screens, where the consistency is lowered by the addition of more white water, which is available at this point. The ultimate screening through holes at least as small as $\frac{3}{16}$ inch in sliver screens, by whatever means accomplished, is very desirable, because it increases the capacity of all subsequent screens and improves the quality of screening.

11. Flat (Scraper) Type of Sliver Screen.—Fig. 2 shows an elementary type of sliver screen, which is used for groundwood only. The various numbered parts are designated as follows: 1, sprocket wheel for chain; 2, scraper; 3, chain; 4, screen plate; 5, shower pipe; 6, stock canal.

The stock runs in canal 6 in the direction indicated by the arrow. A screen plate 4 is placed in the canal and inclined toward the path of the stock. As the stock passes through the screen plate, the coarse fibers are removed by the chain scraper,

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as described in connection with Fig. 1. The screen plate usually consists of punched steel plates, the perforations being about 1 inch in diameter. The rejected slivers are cleaned by a shower of water from the pipe 5 before the scraper dumps them at the end of the plate, and the fibers thus washed off go into the accepted (screened) stock. Very little power is required to operate this screen; from 1 to 2 horsepower is sufficient.

The screen just described would be considered by most manufacturers as a crude sliver screen and inadequate for proper screening, unless used in conjunction with some other type having finer perforations. It is obvious that a sliver screen is unnecessary for chemical pulp, since there are no large slivers, as in groundwood.

12. Rotary Scraper Type of Sliver Screen.—A sliver screen for groundwood of the rotary scraper type is shown in Fig. 3. The numbers designate parts as follows: 1, scraper arm; 2, scraper; 3, screen plate (curved to an arc of a circle); 4, slab grating; 5, tailings canal; 6, stock inlet; 7, shaft for scrapers; 8, shower to clean scrapers.

The stock comes from the grinders through conduit 6 and passes through the grating 4, which consists of flat iron bars on edge, and on which the slabs are deposited. The stock then passes into a spout, which delivers it into the open end of semicircular screen plate 3, and falls by gravity through the perforations in this plate into a tank beneath, from which it is usually pumped to the screen room. Scraper arms 1, mounted on a revolving shaft 7, carry scrapers 2, which are constantly passing over the surface of the screen plate, removing coarse slivers that are too large to pass through the perforations, and discharging them into canal 5, where they are washed by water showers 8. The washings gravitate to the tank below the screen, and the slivers are either collected for further treatment or are thrown away, according to individual mill practice. The scrapers 2 may either touch the plate or may be so adjusted as to clear the plate by a narrow margin, in order to prevent undue wear. This type of screen, equipped with plates having $\frac{3}{8}$-inch perforations and with the minimum allowable spacing between them, has a capacity of about 3000 pounds of air-dry stock per square foot of screening surface in 24 hours, the consistency of the stock being about .8%.

The capacity of such a screen may be considerably increased

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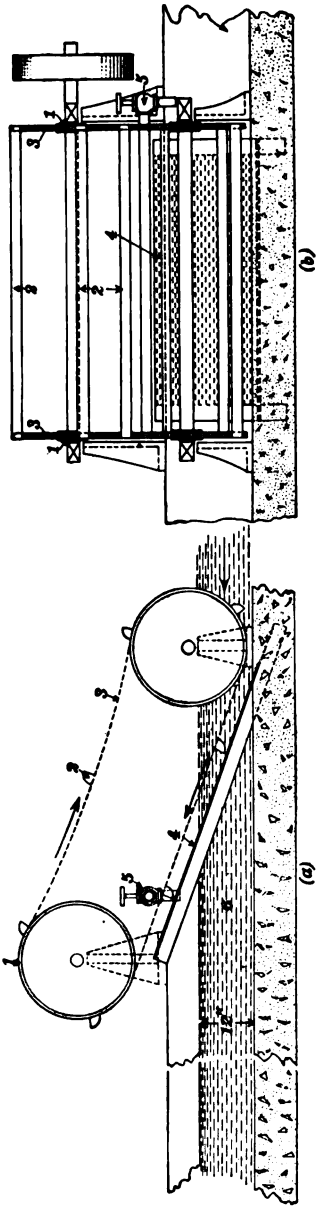

FIG. 2.

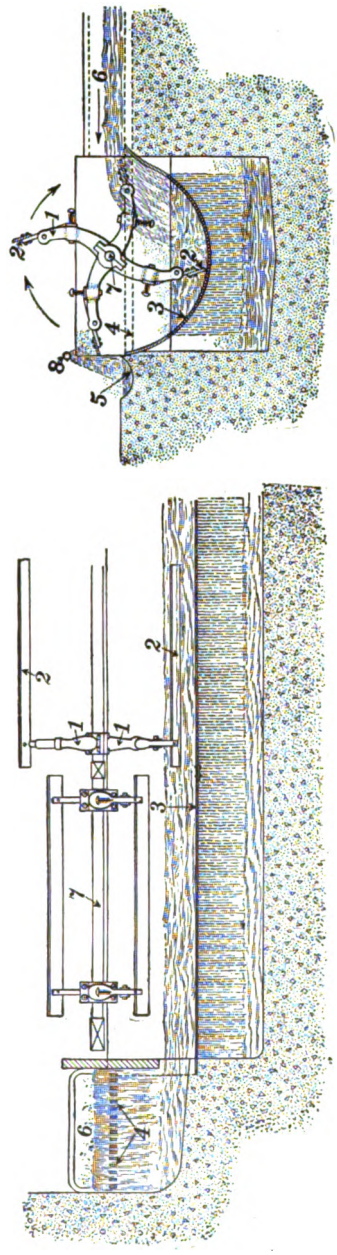

FIG. 3.

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by the addition of automatic shower pipes, mounted on scraper arms just behind the scraper and close to the screen plate. This device may be so designed as to direct a high-pressure shower against the perforated plate while the scraper arm to which it is attached is passing through the arc of the screen plate, and then automatically to stop the discharge during the rest of the revolution.

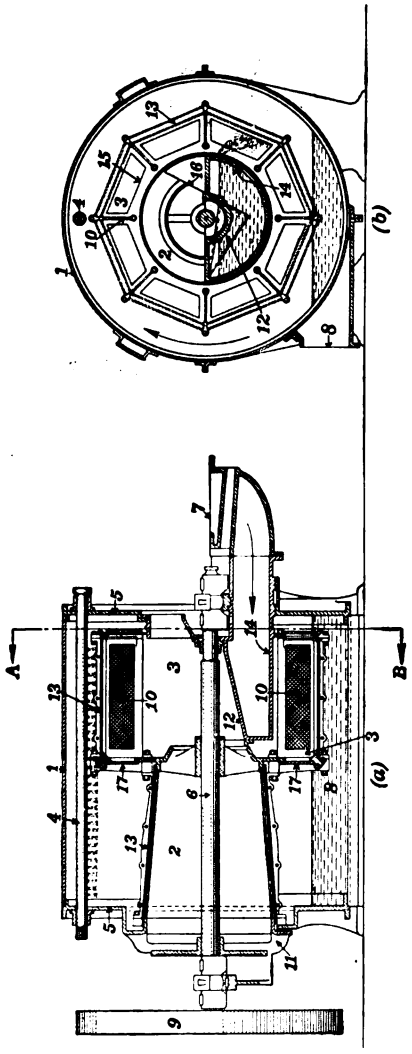

FIG. 4.

The power required to drive a screen of this type, having a capacity of 100 tons per day, is small, from 2 to 3 horsepower approximately.

A modification of this type of screen is also used to some extent. The general arrangement is the same; but the screen plate is mounted on a framework that revolves, and there are no scrapers. The slivers drop from the ascending side of cylinder into a trough.

13. Sliver Screen, or Knotter (Rotating Screen Plate Type).—A sliver screen, or **knotter,** of the rotating screen plate type, which is suitable for both groundwood and chemical pulps, is shown in Fig. 4. The parts designated by the various numbers are: 1, case; 2, second part of runner; 3, first part of runner; 4, shower pipe; 5, end of case; 6, shaft; 7, trough to admit stock to be screened (outer part); 8, spout for accepted (screened) stock; 9, pulley; 10, radial plate; 11, spout

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for rejected tailings; 12, spout from first part of runner to second part; 13, circumferential plate (perforated); 14, trough to admit stock to be screened (inner part); 15, pocket in first part of screen; 16, deflector from trough to first part of screen; 17, end plates (perforated).

This machine consists of a rotating cylinder that is divided into two sections and is mounted on a steel shaft that runs in well-lubricated bearings, the whole being housed in a metal case 1. For all stock, mechanical and chemical (except sulphite stock), the machine is of iron and steel construction, including the screen plates. For sulphite pulp, the plates and framework are made of bronze, to resist corrosion by the acid liquor. The machine is a very simple and compact knotter.

The stock enters spout 7 and its continuation 14, and flows into the inside of the revolving cylinder (drum), or runner, which is divided into two sections, numbered 2 and 3, as plainly shown in (*a*), a longitudinal section. Around the outside of both sections of this drum are secured the perforated screen plates 13. The stock must pass through the screen plates in order to reach the accepted stock discharge spout 8. The first section of the cylinder is divided into eight pockets 15 by radial plates 10. The stock enters these pockets as the cylinder revolves and the pockets come opposite the inlet spout 14. All the stock that is fine enough passes through the perforated plate 13 when a pocket is passing through the lower half of the revolution, and what is left is carried on the radial plates 10 up to a point where it will fall by gravity into a spout 12, which forms an inlet to the second section 2 of the revolving cylinder. This part of the cylinder is smaller in circumference than the first part, but it is covered with perforated screen plates of the same kind, and the perforations are of the same size as those used on the first section. The stock is somewhat diluted by shower water from pipe 4, and has a second chance to pass through the screen plates, after flowing from section 3 to section 2. Note that the second section is conical; this causes the knots or slivers to pass out the larger end into spout 11 for removal to the refiners.

The speed of the cylinder is from 25 to 30 r.p.m., and it requires but very little power to operate it; a 1 h.p. motor is ample.

The machine is very simple in operation, and once the stock supply has been properly adjusted so that no good fiber is rejected, the knotter requires no attention beyond periodical

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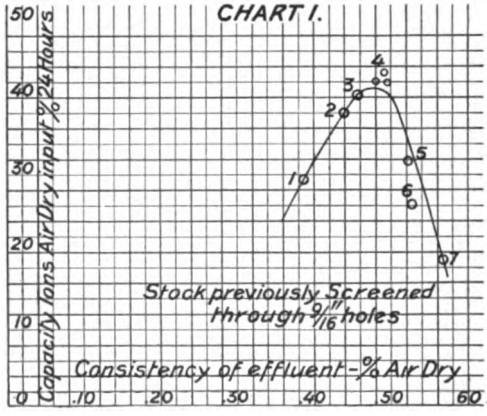
inspection and an occasional cleaning of parts of the screen plates. Its capacity varies with the consistency of the stock and the size of the screen plates.

14. The effect of the consistency of the stock on the capacity of a sliver screen can best be explained by describing an experiment carried out with a knotter (Fig. 4). The first section of plates had 75,840 holes of 3/8 in. diameter, and the second section had 34,048 holes of the same size. The stock had previously been freed from coarse material that would not pass through the 7/16 in. holes in the 1st sliver screen. The quantity of stock screened was measured by passing the effluent over a weir (described in Vol. 2, Section 1) in the box into which the screen



discharged. The consistency of the stock expressed in per cent of air-dry fiber, which was varied from .39% to .565%, was found by weighing representative samples, straining through Fourdrinier wire cloth having 60 meshes to the inch, drying the fiber in an oven, and calculating the weight as air-dry pulp.

The object of the test was to determine the change in the number of tons of groundwood screened per hour as the consistency of the stock increased. The speed remained constant at 26 r.p.m. and the power practically constant at ½ h.p. The amount of stock fed to the screen was kept at such a rate that the rejected stock, or tailings, was practically free from good fibres. When the consistency was .39% the maximum quantity of stock the screen would pass, and still have clean tailings, was shown by the volume and consistency measurements to be 29.6 tons per hour. This is represented by point 1 on Chart 1. Less

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water was then mixed with the stock as fed, and a test showed that the consistency was .44% and the corresponding capacity of the screen was 38 tons per hour, as represented by point 2 on the chart. Similarly point 3 shows a consistency of .455% and a capacity of 40.2 tons; point 4 shows a consistency of about .49% and a capacity of about 42 tons; points 5, 6, and 7 show consistencies of .524% .525% and .568% and capacities of 32, 26.4, and 19.2 tons per hour. A smooth curve is drawn through these points, not attempting to include those which are off the regular track. This curve shows that the capacity of the screen goes up as the consistency increases until a certain condition is reached, and then rapidly falls off. It is evident that the best operation is obtained with a consistency of about .49%, when the capacity will be about 42 tons per hour. If the consistency should fall to .42%, the screen could be expected to handle 35 tons, because the .42% vertical line cuts the curve at its intersection with the 35-ton horizontal line. A test like this shows what can be done with expert operation.

It is important to understand how to make and use such a chart or "curve," which is often more convenient than a table.

SCREENS FOR CHEMICAL PULP

15. Chemical Pulp.—Chemical pulp as it comes from the storage tank contains certain fibers (uncooked chips and knots) that must be removed with as little agitation as possible before any attempt is made at fine screening. Such material is of inferior quality and color, and it becomes broken up into finer units if allowed to pass on to the subsequent processes, where its removal is much more difficult, if not entirely impossible. In theory, this separation of fibers is commonly accepted as correct practice; but many installations are inadequate, as designed, to give as thorough a separation as is desirable.

The consistency of stock leaving the storage tanks is reduced from around 3% or 4% to about ¾% or less by the addition of white water. **White water** is water that has been previously used to convey pulp through the system and has been extracted from the final product for further use; it is sometimes called **re-water.** The proper consistency should be determined for the particular type of knot screen that is to be used, as was previously pointed out in the case of groundwood. It is generally necessary

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to use but one set of these screens, since it is possible to use screen plates having $\frac{5}{16}$-inch round perforations or $\frac{1}{8}$-inch slots, which give very good results. While $\frac{1}{2}$-inch perforations are much more common, they allow a considerable quantity of coarse shives to pass on to the fine screens.

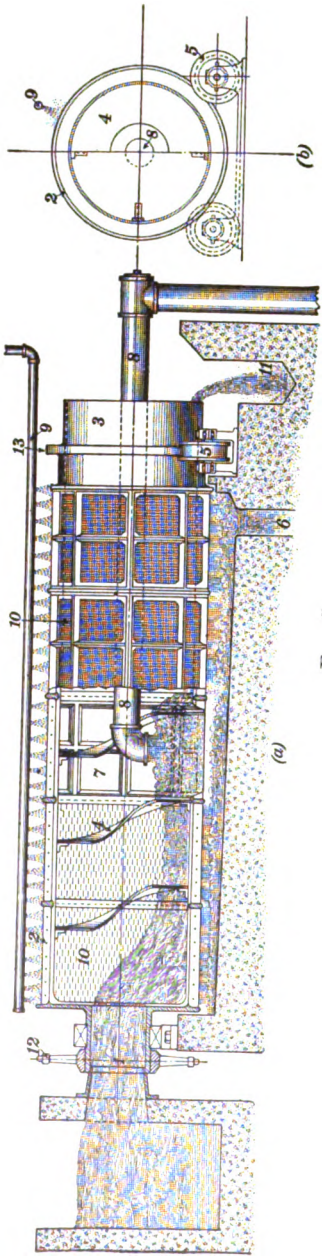

Fig. 5.

Coarse screens having the screen plate secured to a rotating frame, of the same general design as that last described for groundwood and illustrated in Fig. 4, are in general use. Another screen of the same type, but of somewhat different construction, is described below. As supplied by the manufacturers, the screen is equipped with perforated plates throughout its entire length; but it has been found advantageous to alter this arrangement somewhat, in order to use finer perforations and to increase the efficiency and capacity.

The chips rejected by the knotters vary in quantity, depending upon the character and efficiency of the cooking process and the kind of wood used. The quantity so rejected may be as low as 1% or as high as 15% to 20%, in the case of a raw cook.

16. Worm Knotter for Chemical Pulp. — Two views of a worm knotter for screening chemical pulp are shown in Fig. 5. View (*a*) is partly an elevation and partly a longitudinal section; view (*b*) is partly an end view and partly a cross section. The various parts of the machine are designated by

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numbers as follows: 1, stock inlet; 2, cylinder; 3, tailings outlet; 4, worm; 5, trunnion wheels; 6, accepted stock outlet; 7, pan for thinning stock; 8, inside shower; 9, outside shower; 10, screen plate; 11, trough to receive tailings; 12, sprocket.

This knotter is a long cylinder made in sections, each of which is about 2 feet long. These skeleton sections (usually 4 or 5 in number) are all bolted together, and are secured at the ends to cast-iron heads, one of which is hollow and serves as an inlet 1. The hollow part of the head is cylindrical and acts as a trunnion or journal, rotating in a babbitted bearing and supporting that end of the cylinder. The other end of the cylinder carries a track 13, which runs between two flanged trunnion wheels 5, which support that end of the cylinder. The cylinder is driven by a chain and sprocket wheel 12, the latter being keyed to the hollow inlet head 1. Perforated copper screen plates are held in position on the circumference of the cylinder by the framework, as shown in the cut. There are 4 plates, each about $23'' \times 25\frac{1}{2}''$ to each 2-ft. section. Within the cylinder, and attached to the framework, is a worm 4 made of copper plate, which extends practically the entire length of the cylinder. The screen plates are kept clean by showers of water from pipe 9. The knotter shown in the cut is made up of 5 sections but, instead of equipping the middle section with perforated plates as the manufacturers do, it was found advisable to substitute unperforated copper plates at this point, as will be explained later.

In operation, the stock enters the knotter through the hollow head at 1 and immediately tends to run through the perforated plates. The consistency of the entering stock varies, depending upon mill conditions and upon the construction of the knotter; the larger the holes in the perforated plates the thicker the entering stock may be. The maximum and minimum consistencies will be about .8% and .4%, respectively. Since chemical stock is "free," the water tends to leave the stock quickly. As a consequence, particularly if the perforations in the screen plates are fine (say about $\frac{3}{16}$ in.), by the time the stock reaches the middle section 7, so much water has drained away that the stock at this point is too thick for screening. On this account, it has been found necessary to introduce white water here, to reduce the consistency of the stock to a point that will permit further screening in the two remaining sections. It would be impossible to

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thin the stock if perforated plates were used at the point of thinning; hence, unperforated plates are used to enclose the middle section. The knotter is set level, *i.e.*, the axis of the cylinder is horizontal, and the worm pushes out at the front end any heavy material that will not go through the perforations. It is necessary to use a high-pressure shower to keep the screen plates clean, and the shower is directed against the outside of the cylinder, driving back through the holes any material that is lodged in them.

The framework, with the exception of the cast-iron inlet and outlet ends, is made entirely of bronze, and the bolts used for bolting the sections together are also of bronze. Since the cylinder revolves very slowly, approximately 20 r.p.m., the knotter requires but little power to operate it, 3 h.p. being usually allowed for each machine.

The capacity of this form of knotter varies, depending principally upon the size of the perforations in the screen plates. Such a knotter, having $\frac{3}{8}$-inch perforations, would have a capacity of (would screen) at least 50 tons sulphite, soda, or sulphate pulp per 24 hours. With $\frac{5}{16}$-inch round holes or $\frac{1}{8}''$ by $\frac{1}{2}''$ slots, its capacity when using the same class of stock would be about 30 tons per 24 hours. This machine is very simple of operation and requires very little attention for operation or repairs; the regulation of the stock supply is the only adjustment required.

RIFFLING

17. Reasons for Riffling.—The word **riffling** is apparently a misnomer as applied to the treatment of fiber in the paper industry, since the flow of liquid containing the fiber to be treated by this operation must be slow and tranquil. Consequently, the operation is a *settling* process, not one of agitation, as would naturally be inferred from the meaning of the word as ordinarily used. The apparatus in which the process is conducted is called a **riffler** in this country, and a **sandcatcher** in Europe, the latter term being the more appropriate.

The reasons for riffling, or settling, are as follows, considering mechanical and chemical pulp separately:

18. In the grinding of mechanical pulp, which operation is performed on sandstones, particles of the stones continually become loose and are carried along with the ground pulp, unless

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the fibers are first passed over rifflers. The pieces of stone (sand) will pass along with the fibers and eventually find their way into the finished paper, causing small holes in the paper web when passing the calenders.

Besides the sand resulting from the abrasion of the grindstone, mineral matters may be present that have become imbedded in the wood when driving in the river and which have not been removed in barking; also other impurities heavier than water may have found their way into the process, and can be removed only by settling (riffling).

19. In connection with chemical pulp, mineral matters adhering to or imbedded in the wood, as mentioned above when referring to mechanical pulp, may have found their way into the digester; consequently, after digesting, they are carried along with the fibers. Where digesters with mineral linings are used, a gradual process of abrasion sets in; these mineral particles are also carried along with the fibers, and the only way to extract them is by settling, *i.e.*, by passing the stock over a properly proportioned riffler.

Where especially fine chemical fibers are produced, the riffler is a further means for separating the fiber bundles, and it thus facilitates the screening process for certain types of screens.

20. Many systems do not include a riffler, as the amount of material taken out by the riffler is not considered sufficient to warrant the space and expenditure necessitated by it; this is particularly true of groundwood, sulphate pulp, and "news"-grade sulphite systems.

Where the knot screens have large perforations and allow considerable coarse material to pass through with the stock, it is often found, upon washing out the riffler, that a certain amount of this coarse material has been separated and collected along the bottom of the riffler ducts. This, however, is an expensive way of obtaining a result that ought to have been accomplished by the knotter.

21. The Riffling Process.—The riffling process consists in passing the liquid containing the fiber through a long trough having pockets in the bottom, in which the impurities settle. These pockets are usually formed by placing shallow dams or baffles at intervals along the trough. In order to secure the desired effect from this process, it is necessary to have a smooth (sluggish) flow, but care must be exercised that the flow is not so

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slow that the fine fibers will settle. The speed of the flow and the consequent loss of fiber, depend on the depth of the liquid; for if the riffler is too deep, the velocity of flow next to the baffles will be considerably less than the average velocity of the stream, and fiber will settle out. It is therefore recommended that the maximum effective depth be limited to 24 inches, and the velocity at such depth should not be less than 40 ft. per min. By decreasing the depth, the velocity can also be decreased. These are not hard-and-fast figures, as most mill engineers have their own ideas about rifflers.

The consistency of the stock in the riffler would preferably be the same as on the screens, the lower the amount of fiber for a given quantity of water the more effective is the riffling; but, in order to have an appreciable effect from riffling, the percentage of fiber must not be over .8% air dry for chemical pulp and 1% for groundwood.

22. A longitudinal section through a riffler is shown in Fig. 6. *A* is the compartment that receives the stock. *B* is a baffle that

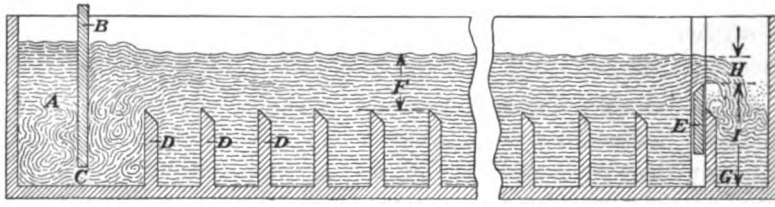

FIG. 6.

can be raised and lowered, thus varying the depth of the opening *C*. By adjusting the baffle *B* to the proper height, a uniform distribution of the flowing stock is secured, and this produces as calm a flow as is possible. The baffles *D* form the pockets for retaining the impurities that have settled out. The height of these baffles is from 4 in. to 8 in. *E* is a dam at the outlet, the height of which is adjustable, so that the working or effective depth *F* (which is the vertical depth from the top of the flowing stock to the line marking the tops of the baffles *D*) of the riffler can be regulated to produce the desired quantity to be passed over the riffler or to secure any other desired effect.

After passing the dam *E*, the stock flows into the channel *G*, whence it is generally passed to the screens. When putting the riffler in operation, it is essential that it be filled with water to

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the overflow height *I* of the dam; otherwise, good fiber will settle in the pockets formed by the baffles *D*.

The depth of the riffler is about 18 in. and the width is from 6 ft. to 8 ft. When the height of the baffles is about 8 in., the distance between them should be about 8 in. or 9 in. The depth *H* of the stock where it flows over the dam is always less than the effective depth *F*.

It is important that rifflers be so constructed that they can be easily cleaned.

Formulas for calculating quantity of flow may be found in the Section on Hydraulics, Vol. II.

23. Riffling Before and After Screening.—From the foregoing explanations, it will be clear that riffling should be done before the fine-screening operations.

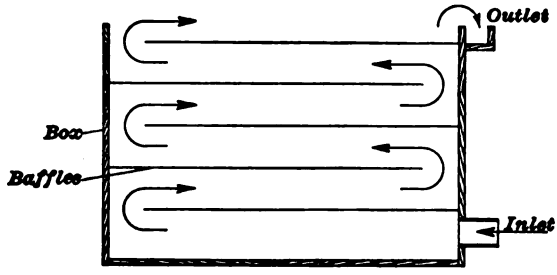

FIG. 7.

The principle of riffling is sometimes made use of for removing the fine dirt, colored particles, and other objectionable matter that remains in chemical stock after screening. Such an apparatus is called a **felt riffler,** on account of its construction; it is used only where exceptional cleanliness is required in the finished pulp. A special grade of cotton felt having a long nap is here used to line the sides and bottom of the riffling channel, and the baffle boards also. The thin stock, about $\frac{1}{4}\%$ consistency, is passed slowly through channels. After about 24 hours of continuous use, the stock is diverted to other channels and the felt is carefully washed by means of a high-pressure hose stream. So much floor space is required for this apparatus that its use is precluded in many mills.

24. A variation of the felt riffler, as sometimes used in the paper mill, is secured by placing the felt-covered baffles horizontally and forcing the stock to rise in a back-and-forth direction, as indi-

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cated in Fig. 7. The baffles are frames on which felt is tacked, and they are held in place by cleats.

QUESTIONS AND EXAMPLES

(1) Why is it necessary to provide storage for pulp?

(2) What is meant by "consistency"? Find the consistency of the stock when the weight of the sample is 1320 grams and the bone-dry fiber in the sample weighs 13.068 grams? *Ans.* 1.1%.

(3) Why is it necessary to screen pulp?

(4) Make a table and a graphic chart showing the weight of air-dry pulp in a 15 ft. diameter tank according to depth. Take points at each foot of depth to 10 ft. and each per cent of consistency to 10%.

(5) What is the mill name for water that has been removed from pulp by the screens? Mention some uses for it.

(6) What difference in character would you expect in the material rejected by the coarse screens for groundwood and for sulphite?

FINE SCREENING

RESULTS SOUGHT IN FINE SCREENING

25. Purpose of Fine Screening.—Up to this point, the object of the screening process has been to prepare the main mass of fibers for the final screening. Assume, for example, that 4% of the stock in the form of very coarse fibers and shives has been removed by coarse screening. There then remains 96% of the original stock to deal with. Of this amount, probably all but 5% consists of fibers of the desired size and quality for the paper-making process. (These figures differ, of course, for different kinds of pulp, and are to be considered here only for purposes of illustration.) The purpose of fine screening, therefore, is to separate this main mass of fibers into two or more grades, according to the length and diameter of fiber required in each. The ideal apparatus is that which will effect this separation in the simplest and cheapest manner.

26. Grades of Pulp.—Different grades of paper require different qualities of pulp. In order properly to design the details of the fine screening system, the maximum length and diameter of fibers allowable must be known or determined, because all fibers of this maximum size and smaller are intended to be segregated

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from the others by the fine screen. The exact dimensions of these limiting (maximum) fibers are seldom expressed in units of length (say decimals of an inch), as it would be almost impossible, commercially, to measure them. The proper standard reached by the pulp is determined by the experience of the paper or pulp maker, having regard for the use to which the pulp is to be put; and *this is controlled by the size and shape of the perforations or slots in the screen plates, by the force used in passing the fibers through them, and by the consistency of the stock.* The standard here referred to does not cover all the physical properties of the pulp; it merely governs the *maximum* size of the fibers.

27. Features of a Fine Screen.—The essential parts of a fine screen are similar to those of the coarse screens; namely, a perforated plate mounted on a frame, some apparatus for forcing the stock against the plate, and a housing or container for these parts. When stock is admitted to the screen, it comes into contact with the screen plates and tends to flow through the perforations. These small perforations (holes $\frac{1}{16}$ inch in diameter or slots about $\frac{1}{100}$ inch wide) offer greater resistance to the passage of the fibers than to the passage of the water in which they are suspended. Therefore, there is an immediate tendency for the fibers to collect around the holes and completely block them. To remedy this, an agitating action must be set up to prevent the separation and to allow the water to perform its only function—that of a conveyor.

28. Points to be Considered in Selecting a Screen.—A screen must perform a definite service; and certain *conditions must be maintained*, under which it is to be operated, if the desired results are to be obtained. In selecting the type of screen to be used, the main points to be considered are: (*a*) cleanliness of output; (*b*) cost of installation, upkeep, and repairs; (*c*) power required per unit of output; (*d*) space required; (*e*) capacity and efficiency of unit; (*f*) conditions necessary for proper operation. Each of these points will be considered in detail.

(**a**) *Cleanliness of Output.*—This means comparative freedom from dirt specks, discolored fibers, etc. These are very often chargeable to the inefficiency of the preceding processes, and their origin should be determined before placing the blame on the type of screen used.

(**b**) *Cost of Installation, Upkeep, and Repairs.*—The first cost of

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a screen is very often given undue consideration by careless buyers. It is only by considering the system as a whole, taking into account the cost of operation and repairs, space and number of units required and efficiency of each, that an intelligent decision can be reached. Conditions vary at different mills, and each mill should be considered separately. Cost of operation and repairs covers the cost of labor, material, and power.

(c) *Power Required per Unit of Output.*—This is usually expressed in horsepower per ton of air-dry fiber screened in 24 hours.

(d) *Space Required per Unit.*—Space required per ton of screened product per 24 hours is another important factor, since each square foot of floor surface represents a considerable expenditure of capital.

(e) *Capacity and Efficiency of Unit.*—It is evident from (d) that it is advisable to have the capacity (output) of each screen as large as practicable. The efficiency should be considered at the same time as the capacity and power. It might be possible to increase the capacity at the expense of efficiency of screening, and it is only after careful tests under standard conditions that the effective capacity of a screen may be determined. This is best illustrated by taking a concrete case:

Suppose a centrifugal screen is capable of passing, under certain conditions of speed, size of screen-plate perforations, and consistency of stock, 15 tons of good stock out of 16 tons delivered to it; it extracts 1 ton of fiber of such quality that it is desirable to reject it, *i.e.*, $\frac{1}{16}$th of the stock going to the screen is rejected. Now suppose that by altering one or more of the conditions, the screen is capable (at an increased power consumption, perhaps) of screening 20 out of 22 tons delivered to it, but that the 2 tons rejected contain a considerable proportion of fibers that should not be rejected. The amount rejected is here $\frac{2}{22} = \frac{1}{11}$th of the stock going to the screen, a considerably greater proportion than before. It is conceivable, however, that it might be advisable to operate under the latter conditions and *re-screen the rejections*, in order that practically all the good fibers of the standard desired may be extracted from the rejections, or **tailings**, as they are called. The two operations may be more efficient in respect to the final result than the single operation first considered.

(f) *Conditions Necessary for Proper Operation.*—It is safe to assert that a large number of screens are being operated under conditions that do not allow of the most efficient capacity being

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realized, due to lack of knowledge of the requirements and inability to control conditions of operation. A careful test ought to be made, if the most efficient results are desired.

29. A Test of a Centrifugal Type of Screen.—A certain groundwood screening system, installed in one of the larger mills of the country, was investigated to determine its efficient capacity per unit and the conditions under which it could be obtained and maintained. The system was considered good; it had been in operation for several years, when an increase in capacity became necessary. A study of the screen was made under the normal working conditions at the mill, with a view to ascertaining: (*a*) power consumption; (*b*) speed of rotation of agitator or impeller; (*c*) consistency of stock; (*d*) quantity and quality of stock accepted and rejected.

It was found that the stock delivered to the screen contained so many slivers (which blocked the screen-plates) that no standard conditions or results could be obtained (*i.e.*, it was impossible to secure uniformity in the quantity and quality of the output), because, after a few hours of operation, the screen rejected a large amount of stock that it ought to have accepted and that it did accept when the screen plate was kept clean. This clogging of the screen plates had been known, but until the test figures were available, its full significance was not realized. This trouble was overcome to a certain extent by the cleaning of the screen plates; but to keep them clean and in proper screening condition, required so much extra labor and expense that it could not be afforded. The problem was resolved into eliminating the objectionable slivers before the stock reached the fine screens, and it was solved by changing the screen plates in the coarse screens, by substituting plates having smaller perforations. It was also necessary to add more screen units, as the use of finer plates decreased the capacity of the coarse screens considerably.

After these changes had been made, a second series of tests showed that the plates of the fine screen could be kept clean for a long period, with the result that there was a marked increase in efficiency and capacity. Thinking that the efficiency and capacity of the screen might be further increased, a change was made in the type of agitator or impeller used, on the theory that the stock was not being evenly distributed over the surface of the screen plates, and that the impeller was "churning" the stock without doing effective work, thereby consuming unnecessary

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power. By varying the speed of rotation of the new impeller, and the consistency, the most efficient conditions were determined for this particular screen system. With the same power consumption, it was found that the capacity was nearly doubled and that the quality of the screening had not suffered.

30. Influence of Consistency.—The beneficial results of adequate coarse screening and the effect produced by the use of the proper amount of force and distribution of stock by the impeller were considered in Art. **29**; it now remains to show what effects may be produced by varying the consistency.

The consistency of the stock at which any screen does its best work must be determined for that particular machine by actual test under operating conditions. If the stock be too thick, the percentage of rejections (tailings) will be too great, and they will contain fibers that ought to have been accepted. If, on the contrary, the stock be too thin, more power will be used to screen the same weight of fiber, and the capacity of the screen will be reduced. The extra water required to dilute the stock to this consistency will have to be handled during the subsequent stages of the process, with resulting increase in power used and decrease in capacity. A better idea of the results obtained under varying conditions may be obtained by reference to the consistency table given at the end of this section. This is a very convenient table, showing, as it does, the amount of water and air-dry fiber in different volumes of stock of varying consistency. Assuming that screening is being carried on at .35% when it might have been done at .50%, the difference in the number of gallons of water handled per ton of fiber at these two consistences is 20,518 gallons, found as follows: Referring to the above mentioned table, the values in column II show the number of gallons of water required to dilute 1 ton of air-dry fiber to the consistency given in column I. According to the table, the number of gallons thus required when the consistency is .35% is 68,154 gal., and when the consistency is .50%, the number of gallons required is 47,636; hence, 68154 − 47636 ÷ 20518 gal. of water additional must be handled when the consistency is .35% than when it is .50%, an increase of 20518 ÷ 47636 = .43+ = 43%. There will be nearly the same increase in power and a corresponding reduction in the capacity of the screen.

31. Consistency Control.—In the majority of cases, the operator judges by sight whether the consistency is high or low,

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and increases or decreases water accordingly. It is possible to regulate automatically, within reasonable limits, by use of the apparatus described below, the consistency of stock coming from the storage tanks before screening. As previously stated, this stock may be 3% air dry, and means have been found for keeping stock of this consistency fairly uniform. Starting, then, with this regulated stock, if the quantity being used at any time while adding a continuous supply of the proper amount of water, can be determined, the mixture must be of a fairly uniform density (consistency). The problem thus reduces to finding some means of measuring the *amount* of stock of a certain density, which is to be continuously diluted by the requisite quantity of water to the consistency desired. The writer knows of no better method of controlling the consistency of stock as thin as .5% than by use of the mixing box shown in Fig. 8, to which the reader is now referred.

Referring to Fig. 8, F' is the feed pipe for the regulated stock; F'' is the feed pipe for the water used to dilute the stock; S is the stock-measuring box; W is the water-measuring box; M is the mixing box, where the stock and water mingle; G' and G'' are gates, which can be raised and lowered to control the supply of stock and water admitted to mixing box M; O' and O'' are outlet pipes for the excess stock and water, respectively; O is the outlet pipe from the mixing box M; A' and A'' are worm gears that are operated simultaneously by the wheel B; X and Y are the openings from the measuring boxes S and W, respectively, to the mixing box M.

The operation of the apparatus is as follows: More of the regulated stock than is required is pumped into the box S, filling the right-hand part to the top of the baffle plate P', which it then overflows and the surplus runs out through the pipe O'; the gate G' is raised to such a height that just enough stock flows into the mixing box M to keep the overflow height in measuring box S at a constant height; in other words, it keeps the head h' on the center of the opening X constant, and thus admits a constant supply of stock to the mixing box. The same effect is secured, and by the same means, in admitting water to the mixing box from the water-measuring box W, under a constant head h''. The heights of the gates G' and G'' are so adjusted that the proper supply of stock and water is admitted to the mixing box to produce stock of the desired consistency. If the flow of stock and

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water should vary, or if the overflow is greater than is desired, the gates G' and G'' may be raised or lowered simultaneously, by turning wheel B, until they are situated at the proper height.

32. There may be variations in the method of applying the principle just described, but more uniform results are achieved than can be obtained by the eye of the operator. The results of a typical consistency test for a centrifugal screen on groundwood are shown in Chart 4 (Art. **41**); such charts illustrate very forcibly the necessity of consistency control.

From what has preceded, it is obvious that an increase in the consistency tends to lower the power consumption per ton of pulp fed in; but in securing this result, there is an increase in the proportion of tailings. As it may become necessary to screen the tailings again, there is evidently a point in the process where the saving in power is balanced by subsequent losses elsewhere; the consumption of power does not decrease, while the amount of tailings increases rapidly.

33. No. 2 and No. 3 Grades of Stock.—The chart referred to above shows that the tailings from the fine screens may amount to as much as 10%, in which case, it may be advisable to re-screen, removing such fibers as are not too coarse. The coarser fibers then left are diluted with water, usually white water, and by use of screen plates having larger perforations or slots, a second or third quality of stock is produced. This stock may be refined and reduced to the standard desired or it may be disposed of for special uses in different grades of paper.

34. General Difficulties.—Aside from those already discussed, the usual troubles attending screening operations are: broken screen plates, improperly fitted plates (allowing leaks of unscreened stock into the screened stock), difficulty of keeping plates clean (this applies more particularly to the screening of groundwood, and is more pronounced in certain types of screens), and the foaming of chemical pulp if the acid has not been properly removed in the blow pits.

The remedy suggested for broken or improperly fitted plates is frequent periodical inspection of the stock accepted by each screen. Various methods of doing this are in use. One that is simple and effective consists in passing a pailful of screened stock through a piece of wire cloth of about 10 mesh; the majority of the finer particles readily pass through, leaving a film on the wire

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cloth. If held before a strong light, slivers are quite easily distinguished.

The cleaning of screen plates will be considered in connection with the description of the various types of screens.

The foaming of stock is usually remedied by the addition of small amounts of some liquid, such as kerosene or anti-foam oil, which lowers the surface tension of the stock solution. In

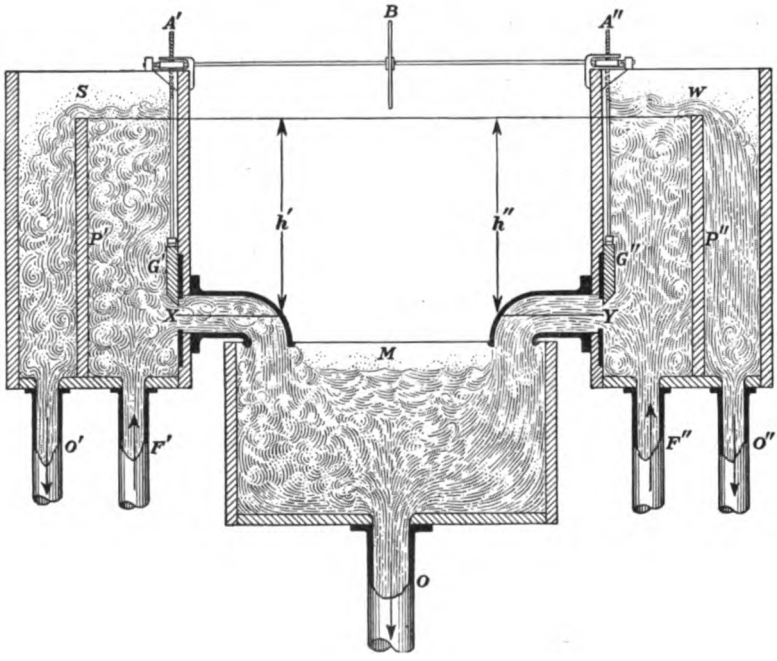

FIG. 8.

these circumstances it is also advisable to use cold fresh water to dilute the stock and allow as much white water as possible to escape to the sewer, thereby removing the trace of acid that causes the trouble.

TYPES OF FINE SCREENS

35. Diaphragm or Flat Screen.—A type of screen that is extensively used in the pulp and paper industry is the **diaphragm screen,** which is often called a **flat screen,** because all the plates lie in the same plane. This plane is either parallel to the floor

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of the room (horizontal) or it may be inclined downward slightly, to aid the stock in flowing over the plates. The term *diaphragm* is applied to one of the most important parts of the screen, and from it, the machine takes its name of diaphragm screen.

A screen of this type is shown in Fig. 9, (*a*) being a longitudinal section and (*b*) a cross section. The various parts designated by numbers are: 1, pulley; 2, shaft; 3, bearings for shaft; 4, adjustment nuts for diaphragm mechanism; 5, diaphragm plunger, or pitman; 6, screen frame; 7, wooden shoe; 8, grease box for cam; 9, clamp for shoe; 10, screen box; 11, flow box; 12, screen plate; 13, strips around edge to help secure screen plates; 14, wooden clamp for diaphragm (lower part); 15, wooden clamp for diaphragm (upper part); 16, passage to flow box; 17, beam to carry bearings and grease boxes; 18, frame to which diaphragm is attached; 19, cross pieces of above frame; 20, cross pieces of screen box; 21, cross pieces of screen box (these support the screen plates); 22, diaphragm (rubber); 23, wooden connection between diaphragm board and plunger; 24, cam; 25, supporting arm for springs; 26, ball and socket joint; 27, arm bearing on shoe to make it follow cam; 28, adjusting springs; 29, spring to keep shoe on cam; 30, side strip to which end of screen plate is screwed; 31 and 32, fixed and movable parts of adjustable slide dam.

36. The diaphragm screen depends for its operation upon a combination of gravity flow and suction. The stock flows into one end of the screen box 10 and passes toward the other end over the screen plates 12. As the fibers pass over the screen plates, the *accepted stock* passes through the slots or perforations and runs into the space between the plates and the diaphragm 22, from whence it gravitates by the way of the passages 16 to the flow box 11, where the adjustable dam 31, 32 regulates the back pressure on stock under the screen plate and varies the effective head that induces the flow accordingly. Enough stock is admitted to the screen to keep the upper surface of the screen plates covered. Then the vibrating motion given to the diaphragm 22 by the cam mechanism 5, 7, 24, which causes the diaphragm to rise and fall, creates a partial vacuum in the compartment under the screen plates, thus causing a flow of stock through the slots or perforations. A greater volume of stock must be admitted to the screen than it can possibly accept (screen), because a fairly rapid flow must be maintained over the surface of the plates, which must be kept covered with a thin

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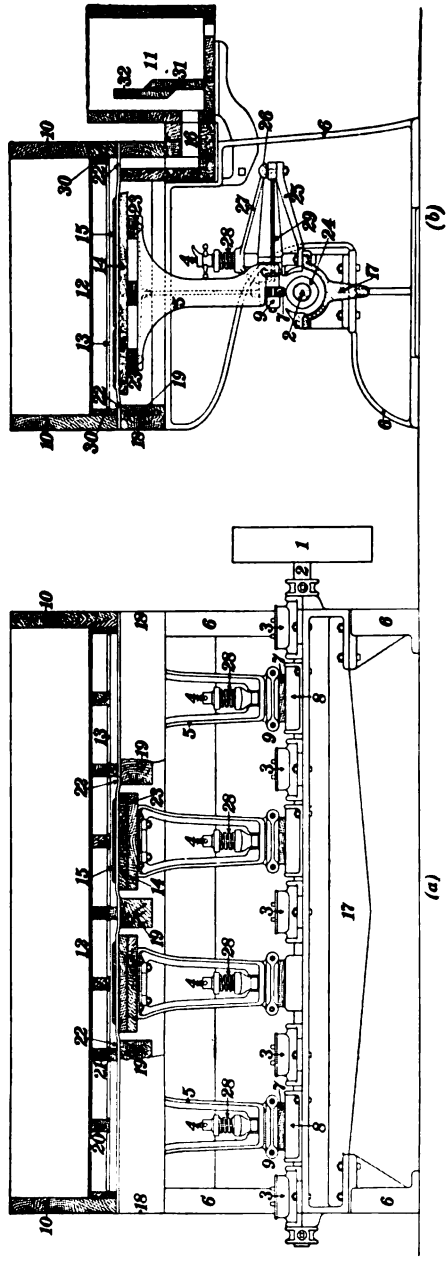

Fig. 9.

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layer of stock to maintain the vacuum and insure proper operation. For this reason, the rejections, or tailings, from a single screen of this type are very large and contain much good fiber. To cut down the final rejections to a reasonable amount, several screens are connected, end to end, each delivering the unscreened pulp to the next in succession. Such a battery of screens (usually 3 or 4 screens to a battery) is so arranged that by the addition of showers directed either against or with the current of stock across the plates, the fibers are prevented from settling, and good fibers are washed from shives and knots. Finally, the coarse fiber and tailings run out of the battery of screens at the opposite end to that from which the stock was admitted. The accepted stock is discharged, of course, from flow box 11.

37. The size of the screen box depends upon the size and number of screen plates to be used; that is, the box is wide enough to allow the screen plate to be placed lengthwise across it and is long enough to contain the combined width of all the screen plates it is desired to put in it. A convenient height for the sides of the box is 2 feet above the level of the diaphragm. The joint at the level of the diaphragm, between the screen box and the diaphragm frame 18, is generally hinged on heavy hinges, which are placed on the side opposite from the flow box, thus permitting the upper part of the screen box to be tilted at regular intervals, when the plates and passages are thoroughly washed from beneath with a high-pressure stream of water, to prevent the formation of slime.

For sulphite pulp, where the stock to be screened contains acid, the screen plates are made of bronze; but for groundwood, sulphate, and soda pulps, they are made of brass. A single plate is about $3\frac{1}{2}$ feet long, 1 foot wide, and about $\frac{3}{8}$ inch thick. The slots, which are wider at the bottom than at the top, are usually about 4 inches long and are arranged about 4 or 5 to the inch. The width (or caliper) of the slots varies with the kind and quality of the stock to be screened, and this dimension must be determined by each mill, according to the fiber it wishes to get. For first quality fiber, the width might range from .008 inch to .012 inch, for mechanical, sulphite, and soda pulps, and for screening the stock in the paper mill; for second quality fiber, widths from .011 inch to .015 inch, or even wider, are used. For sulphate pulps, wider slots are used than those just mentioned.

The diaphragm 22 is a sheet of special rubber that is about

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¼ inch thick; it is fastened to the screen frame with nails or screws.

38. The diaphragm screen is simple in operation. The shaft 2 of the agitating element is driven at about 125 to 175 r.p.m. Stock is admitted at a consistency dependent upon the work demanded of the screen by the general screening system; the finer the slots are in the plates the thinner (lower) the consistency must be. With the mechanism and screen plates in good repair, the only problem is to keep the screen plates clean. Scrapers, either hand or mechanical, are frequently used on diaphragm screens, especially those screens that are used on tailings. Screens of the inclined type (those with the screen plates inclined instead of horizontal) have a tendency to be self cleaning. A hand scraper is simply a piece of board about 6 in. by 18 in., with a long handle. The mechanical scraper consists of slats, which may be dragged over the surface of the screen in the direction of the flow of stock or may be pushed back and forth by oscillating arms.

The one advantage of the diaphragm screen is the cleanliness of the output. The approximate amount of stock that can be screened per plate is from .275 to .4 tons in 24 hours, or more if the slots are large; the amount varies with the kind of fiber and other conditions.

39. The low capacity (output) for the size of the apparatus, involving as it does a large number of moving parts, results in a high cost per ton screened. Also, where economy of space is a factor, the diaphragm screen takes up a relatively large amount of room per unit of production. The power per ton screened varies, a 12-plate screen requiring about 3 h.p.

The cost of operation of flat (diaphragm) screens is high as compared with centrifugal screens. No general authoritative information is obtainable as regards capacity at different consistencies, per cent of tailings (or rejected stock), and so forth, but the following figures are indicative of the cost of operation and repair as compared with centrifugal screens. The figures are taken from records kept at a mill where flat screens were replaced with centrifugal screens: Operating and repair cost per ton screened for flat screen was $1.12; for centrifugal screen, the cost was $0.21.

The flat screen requires a large amount of attention while

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running, to keep the slots in the screen plates clear and to adjust the flow of stock. It is necessary to open the screen box frequently, to clean inaccessible passages where slime tends to collect. The wooden construction and the large number of moving parts necessitate a large amount of repairs.

Inspection of the screen while running should be (1) of the accepted stock, to determine the presence of coarse fibers, which indicates broken or ill-fitting screen plates, which should be searched for when their presence is suspected; (2) inspection of rejected stock, which may contain too much fine fiber, indicating clogged screen plates or the admission of too much stock to the screens; (3) for mechanical troubles.

Methods of fastening screen plates vary; for security, screws at 5-inch or 6-inch intervals around the plate are used. A single bolt in the center of the joint between two plates not only gives security but also makes it easy to remove the plates; a number of patent fasteners are designed for the same purpose.

40. Horizontal Centrifugal Screens.—Figs. 10 and 11 show a longitudinal section and a cross section of two horizontal centrifugal screens. Both machines operate on the same principle, but their construction is different. The numbers listed herewith refer to parts of either machine: 1, outside casing; 2, pulp inlet; 3, distributors; 4, bearings; 5, shaft for runner or impeller; 6, impeller blade; 7, white-water shower inlet; 8, dome; 9, tailings outlet; 10, accepted stock outlet; 11, screen plate. Referring to Fig. 11 only, 12 is the plate cleaning shower, and 13 is a case enclosing gearing for rotating screen plates while cleaning.

These screens are operated by the action of centrifugal force, which drives the stock against the encircling screen plates, through the perforations, to the outside. The principle is simple: whenever a body is caused to revolve, it tends to move *away* from the center of rotation, and the faster the speed of rotation the greater is this tendency, *i.e.*, the greater is the centrifugal force. In the present case, there is no force acting on the stock tending to force it toward the center, with the result that the stock is thrown radially outward, forced against the enclosing screen plates, and through the perforations.

The stock enters through the inlet 2, Fig. 10 or 11, and is separated into several streams by the stationary distributors (compartments) 3, from which it flows to the impeller blades 6; this insures a much better distribution of the stock, breaks it up as it

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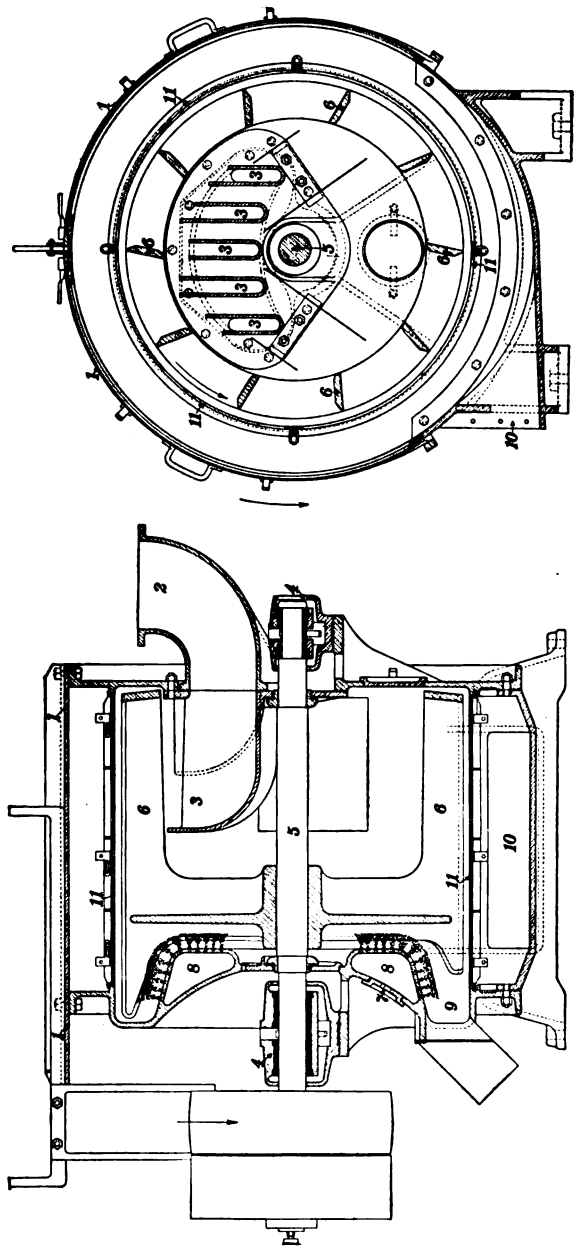

Fig. 10.

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were, than if it flowed in a single stream to the impeller blades. This matter of distribution is important, since it has a direct bearing on the capacity, horsepower consumed, and the efficiency of the screen. In Fig. 11, the stock enters from both sides of

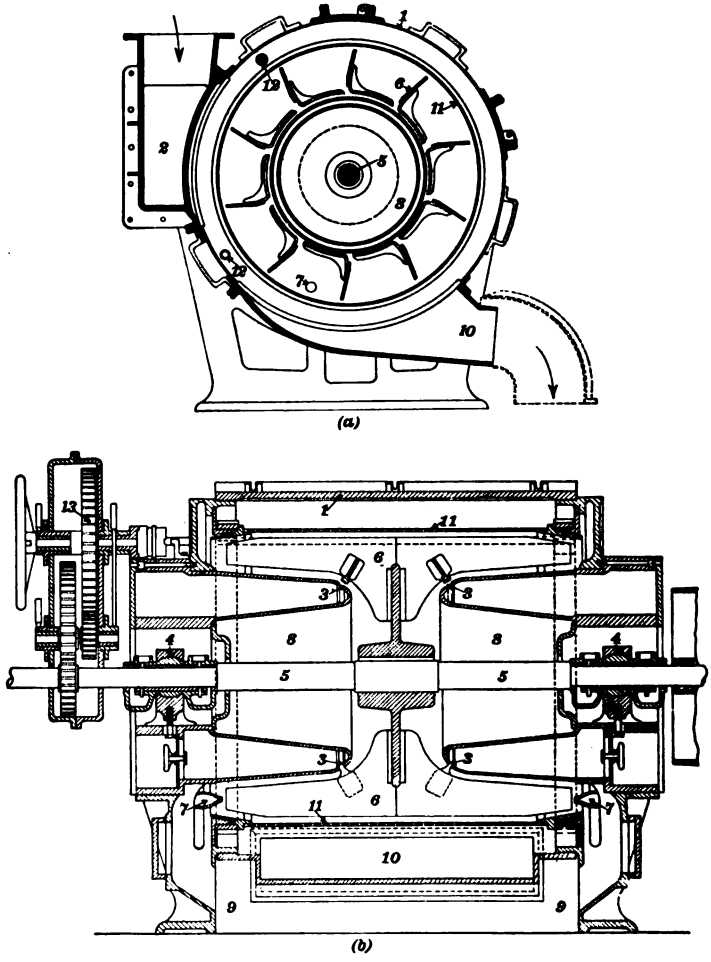

FIG. 11.

the center through the orifices 3. Impellers, as well as distributors and manner of introducing stock, vary in design, and these are the chief differences in this type of screen, as made by various manufacturers. The impeller, or agitator, consists of a shaft

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with blades set at regular intervals around it; it is generally made of cast iron for use with all classes of stock except sulphite, when bronze is advisable, to resist the acid. The impeller should rotate at a speed that has been predetermined to suit the conditions and the class of stock to be screened. The screen plates 11 are usually rolled copper sheets, perforated with holes varying from .05 in. to .07 in. or larger in diameter; a common size for groundwood, sulphite, and soda pulps is $\frac{1}{16}$ in. (.0625 in.). For the screens here shown, the screen plates are secured to the frames, which are bolted to the screen body. In some designs, provision is made for the rotation of the screen plates at a slow speed, to facilitate cleaning them.

The accepted stock passes through the plates and falls by gravity through the space between the plates and the casing to opening 10, which is a discharge spout. The fibers that are too coarse to pass through the perforations in the screen plates are thrown off from the impeller by the short wings at the back of the machine shown in Fig. 10 or from the ends of the inclined blades of the machine in Fig. 11, and they find their way out of the tailings spout 9. The rear head of the machine shown in Fig. 10 is hollow, as indicated by 8, and one side of the chamber thus formed is perforated, thus providing a shower when water is forced into the chamber. In the case of the machine shown in Fig. 11, the water is introduced through the shower nozzles 7. This shower plays an important part in the operation of this type of screen. The water is introduced at this point to wash the coarser fibers that have been forced to the end of the screen by the action of the impeller blades, thereby washing out some of the finer fibers from the coarser ones and increasing the screening efficiency.

These screens are designed for continuous operation and require but little attention. The only running adjustments that are necessary are those for securing uniformity in the amount and consistency of the stock supplied. Inspection should be made of the accepted stock for coarse fibers, the presence of which indicates a broken or leaky screen plate. Likewise, inspection should be made of the rejected stock for fine fibers, the presence of which indicates that the consistency of the supply is too high, that too little shower water is used, or too large a quantity of stock is being admitted to the screen. This latter will also be indicated by increased power consumption.

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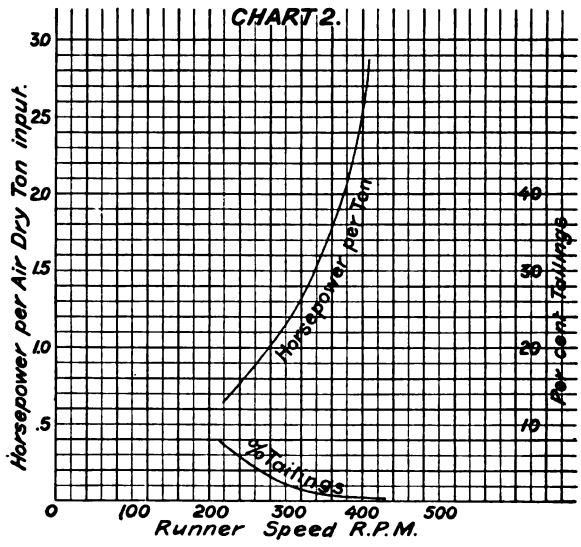
41. The following graphic charts indicate capacities and power consumption with varying consistencies of stock for certain specific types of horizontal centrifugal screens under conditions as stated. Screens of the same design under different conditions and screens of different designs would have to be thoroughly tested, in order to determine their capacity and power consumption. These charts are inserted here to illustrate the necessity of exact knowledge of the governing factors; they are, in a general way only, applicable to all screens of this type.



The effect of varying factors is shown in Charts 2, 3, and 4. Chart No. 2 illustrates what happens to the power consumption and percentage of rejected stock (tailings) when the runner speed of the centrifugal screen handling *groundwood* stock is increased. The curves are based on the number of revolutions per minute for three differen tspeeds of the runner (impeller), the corresponding H.P. consumed for each ton of air-dry pulp fed to the machine, and the percentage of tailings. It will be seen that the power requirement increases rapidly and also that the percentage of tailings decreases, but less rapidly, as the speed increases. This may be easily explained, because it is evident that the higher the speed of rotation the greater must be the power required to drive the runner; also, as the speed of the runner

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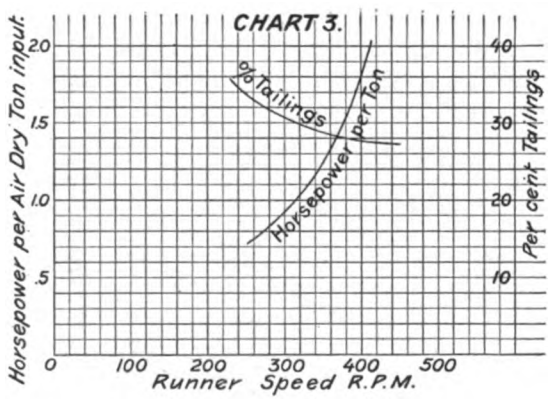
increases, the centrifugal force throwing fibers through the screen will increase and the tailings will naturally be less on that account.

Chart No. 3 shows the effect of increasing the runner speed on the horsepower consumed per ton of air-dry pulp fed to the machine, also the percentage of tailings when screening *sulphite pulp*. On both of these charts, the vertical figures at the left represent horsepower (h.p.) consumed and the figures at the right represent percentage of input that is discarded as tailings. The chart is read as follows: Assume that it is desired to find the horsepower (h.p.) consumed and the percentage of tailings in groundwood pulp that is being screened with a runner speed of 300 r.p.m. The vertical line from the 300 figure at the bottom



crosses the power curve at a point which corresponds to 1.18 h.p. per ton of input and crosses the tailings curve at the 2% line. Similarly, for sulphite pulp, extend the horizontal to the left from the point where the vertical line at 300 revolutions crosses the power curve and find that the power consumed is .94; it crosses the tailings curve at 30%. Therefore, by increasing the speed to 400 revolutions, about 2% on the tailings is saved at an expenditure of .86 h.p. extra per ton of input. The sulphite tailings in the test from which these curves were obtained are high, because of the desire to obtain maximum cleanness in the accepted stock. By increasing the shower water in the screen, more of these could have been washed through. Furthermore, the plate perforations were finer than usual.

In these tests, the consistency of the stock in each case was .5% air dry. The screen plates for groundwood had a total

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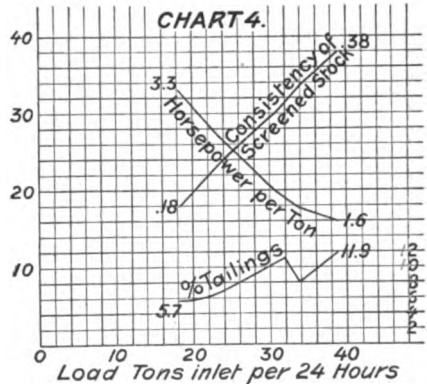
area of 3360 sq. in., with 324,000 holes, each .0625 ($\frac{1}{16}$) inch in diameter; while the plates for sulphite had the same area, but contained 358,000 holes, each .0550 inch in diameter. The groundwood screen took 30 horsepower while that for sulphite consumed 375 horsepower.

Chart No. 4 is more complicated, and shows the mutual change in the various factors of importance in screening. In this case, a centrifugal screen, with plates perforated with .065-inch holes, operated on sulphite pulp at a constant speed of 388 r.p.m. In this test, the consistency of the screened stock was changed from .18% to .38%. At the start we find the horsepower per ton is 3.3, and the tailings were 5.7% of the input, while the quantity



of stock fed was 18 tons per 24 hours. On increasing the consistency to .24%, the horsepower per ton dropped to 2.7, while tailings increased to only 6.2%. On further increasing the consistency, the horsepower gradually fell off to 1.6 at the end of the test, while the percentage of tailings had increased to 11.9%. The temporary drop in the tailings is not explained in the data, but may have been due to a thorough cleaning of the plates or even to a difference in temperature or in the character of stock from another digester. It will be noticed that the power consumption curve drops off less and less rapidly as the consistency of the stock is increased. This indicates that the point is being approached at which a further increase in consistency will not cause a decrease in power consumed and that from there on, the power consumption will increase if the consistency be raised.

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This study of curves thus brings to light many important points in the operation of pulp mill machinery.

42. Vertical Type of Centrifugal Screens.—There are a few

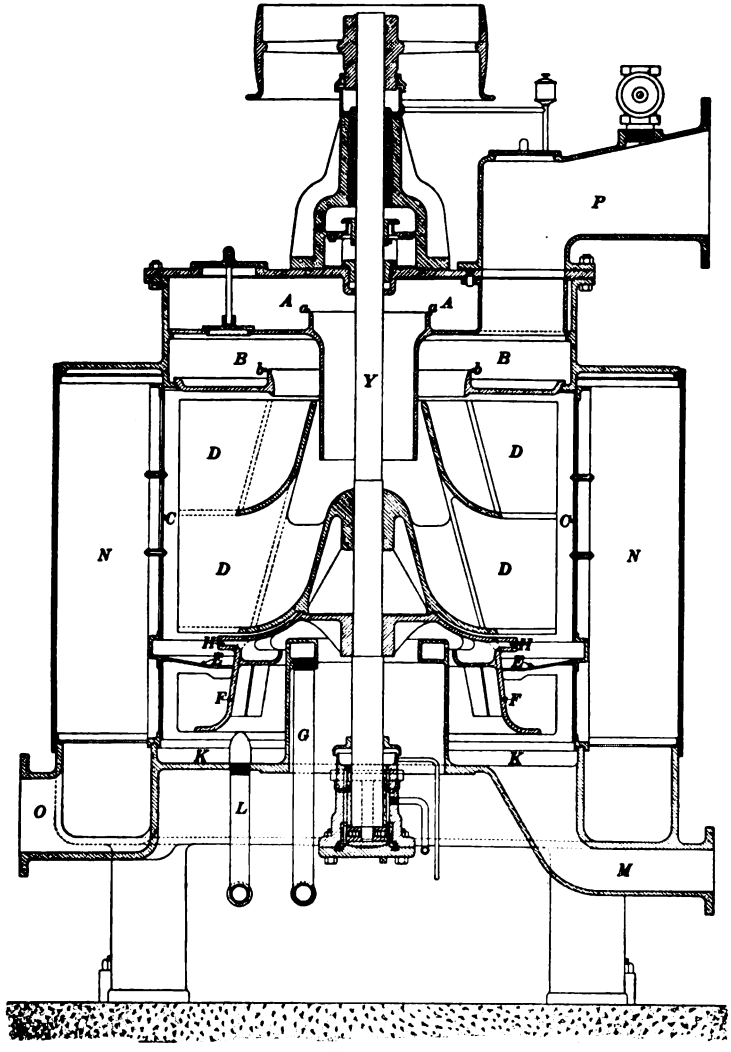

FIG. 12.

screens on the market in which the axis of the shaft carrying the impeller is vertical instead of being horizontal, as in the case of the two machines described in Art. **40**; these belong to what is called the vertical type of centrifugal screens.

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A centrifugal screen of the vertical type is shown in Fig. 12. The pulp (stock) enters the screen through the inlet *P* and is discharged into the two chambers *A* and *B*. The stock overflows the two circular rims *a* and *b* and passes from the chambers *A* and *B* to the upper and lower parts of the double runner, or distributor, *D*, which is rigidly connected to the shaft *Y* and turns with it, thus causing the stock to be thrown against the screen plate cylinder *C* by centrifugal force. The tailings, and what good fiber may not have passed through the screen plates, fall down on the table *E*, where they are diluted with water that enters the tailings runner *F* through pipe *G* and is thrown out through the nozzles *H*. In this diluted state, the tailings flow down on the wings of runner *F*, and they are thrown against the screen plates *C* for the second time. The washed tailings then fall to the bottom of bowl *K*, where they are washed by water from pipe *L* and are finally discharged through the tailings outlet *M*. The accepted stock passes through the screen plates *C* into chamber *N*, drops to the bottom, and is discharged through the accepted stock outlet *O*.

The screen-plate cylinder is made in four sections, which are held together by steel clamps. The screen plates rest on frames on leather cushions, which allow the necessary vibration. The screen has hand holes, for inspection and cleaning. The inlet *P* is provided with a gate valve, for dilution of stock, if desired.

43. Inward-flow, Rotary-type, Screen.—There are several makes of what are known as inward-flow, rotary-type, screens, which differ slightly in mechanical design and in the type of agitating element used. This type of screen has not heretofore been extensively used in American pulp mills for the fine screening of groundwood and chemical pulps, but several installations of these screens are now in operation. Their efficiency under the working conditions that prevail on this continent has not as yet been determined. This type is used almost entirely in connection with a paper machine, where a screen is required to break up fiber bundles and to keep foreign material from reaching the paper machine. In this latter case, the pulp stock is supposed to be properly screened before being sent to the paper machine, and a screen is used more as an insurance against accident due to the presence of some foreign material that may have found its way into the prepared stock during its manipulation in the paper mill.

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44. Fig. 13 shows a cross section (*a*) and a partial longitudinal section (*b*) of an inward flow, rotary screen. The principle under which this machine operates is that of gravity combined with a slight suction. The different parts are numbered as follows: 1, vat; 2, cylinder; 3, polygonal drum; 4, gutter for spray; 5, stock inlet; 6, bearing; 7, accepted-stock outlet; 8, tailings doctor; 9, tailings spout; 10, cleaning outlet; 11, shower; 12, casing.

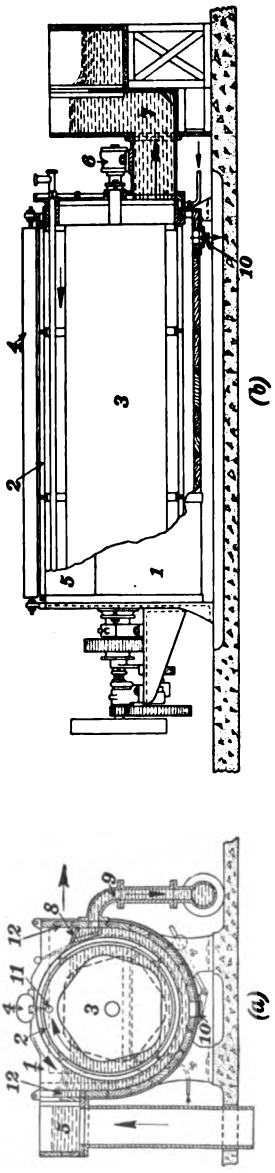

FIG. 13.

The stock is admitted through inlet spout 5 to the space between the casing 12 and the screen-plate cylinder 2, which is slowly turning in the direction of the arrow. Inside the screen-plate cylinder is a polygonal drum 3, which rotates in a direction opposite to that of the screen-plate cylinder. A cross section of the drum has the shape of a pentagon, with the vertexes rounded. The drum is not entirely submerged in the stock, the result being that the free surface of the stock rises and falls slightly, which causes a slight suction in the space above the free surface, and thus helps the flow of stock through the screen plates into the inside of the cylinder. That this action may be better understood, suppose the drum to be in the position shown by the full outline in (*a*) and that the same volume of stock is always present between the drum and the screen-plate cylinder. Now, if the drum is not entirely submerged, as is the case when the machine is running, the area of the drum (cross section) beneath a horizontal line through the center will be greater than when the drum occupies the position indicated by

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the dotted outline in (*a*). The result is that the volume of the space between the drum, the screen-plate cylinder, and under the horizontal diameter is *less* when the drum is in the position indicated by the full outline than when in the position indicated by the dotted outline. The liquid (stock) is therefore crowded into the space above the horizontal diameter while the drum is passing from the dotted-line position to the full-line position by an amount equal to the difference in volume mentioned above, and this raises the level of the free surface of the stock, which falls again during another one-fifth of a revolution.

The coarse fibers that remain on the outside of the screen plates are removed by a shower and doctor at 8 and are washed into the tailings spout 9. The slots in the screen plate are cleaned by shower 11, which is located inside the screen-plate cylinder, and which forces a jet of water through the slots and up into waste pan (or gutter) 4. The accepted stock passes out through opening 7 at the end of the screen, and the box to which this opening is connected is fitted with an adjustable dam for the purpose of regulating the height of the stock in the screen-plate cylinder.

Other screens of this type are all based upon the same principles, but are of slightly different design; they accomplish similar results, the difference between them being largely in simplicity and ruggedness of design, difference in method of creating suction, and in the removal of the rejected stock.

45. Rotary-type Screen (Slow Speed).—It is not intended to describe here all the screens of this type. There is a growing demand for a screen for the fine screening of pulp that will be so constructed as to require much less power per ton; and it is safe to predict that, under favorable conditions, such a machine is possible. In fact, the screen described below is being successfully used as a *re-screen*, and has shown under test the possibility of its use as a fine screen.

46. Tailings Screen.—The chief object of a tailings screen is to separate all good stock from the tailings of fine screens and reject only clean slivers. Tailings are difficult to screen, because the action of the preceding screening operation interlocks the slivers and forms clusters, which hold good stock. The effects of consistency of the supply are more pronounced, and it is therefore very important to control the consistency in the case of machines

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used for screening tailings or else to work the machines a little below the maximum capacity, to insure good operation at all times. The tailings screen was specially designed to meet the peculiar conditions encountered in handling tailings. Tests taken with the machine operating as a *second screen*, *i.e.*, screening the rejections from centrifugal screens, were run so that the tailings did not exceed 2% of the production or the total amount of good stock from the centrifugal screens, when the machine was run up to capacity. This figure is used by many mills as a standard for the permissible amount of final rejections. For instance, the machine screened 7 tons of good stock from the rejections of the centrifugal screens and rejected 1.4 tons of slivers. The centrifugal screens were handling about 71 tons and rejecting 12% of that. The final rejections, 1.4 tons from the tailing screens, are about 2% (1.4 ÷ 71 = .02 very nearly) of the amount handled by both sets of screens.

47. The principle employed in this machine is very similar to that made use of in the knotter, but its action is compounded several times; it therefore has, to some degree, the main characteristics of the knotter. The machine, see Fig. 14, consists of a casing A, within which revolves a screen drum B. The interior of drum B is divided into pockets or compartments C, which decrease in size as they near the tailings end of the machine, see view (b). This drum rotates on two rollers E at either end, the rollers being mounted in roller bearings. Located centrally inside the drum is a stationary trough or compounding box F, see view (b), which is also divided into compartments, to correspond with the compartments in the rotating drum.

The stock enters through inlet G into the first compartment of the compounding box F and is delivered from this compartment over apron H into a corresponding compartment in the rotating drum C. The impact of the stock against the screen plate I screens a considerable part of it. The unscreened residue from the first compartment is carried by the rotating drum on radial partitions to the top of the machine and dropped into the second compartment F_1 of the compounding box; from here, it is again delivered over apron H into the corresponding compartment of the rotating drum. This action continues through the remaining compartments of the compounding box and the drum until all the good stock is removed and the rejections are discharged through the outlet J. This explains why the action is com-

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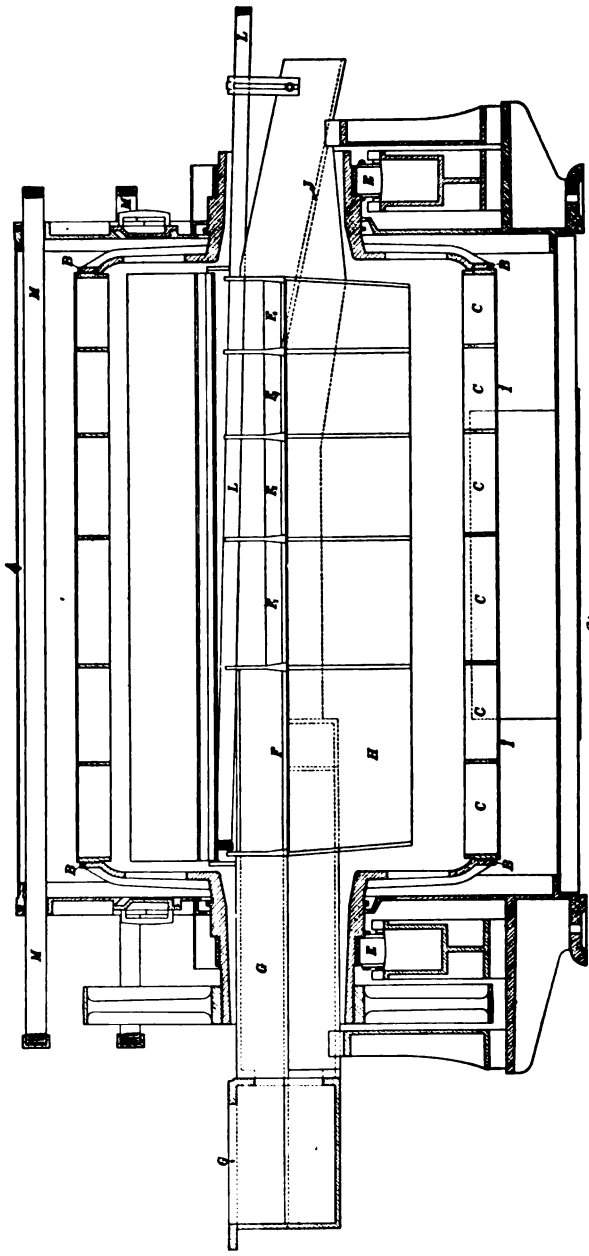

(a)
FIG. 14.

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pounded and why the compartments become smaller as they approach the tailing end of the drum, since each compartment has a smaller amount of stock to handle than the preceding one. The accepted stock passes through the plates throughout the entire screen drum and is discharged through the outlet *K*, see view (*a*). Shower pipe *L* dilutes the unscreened residue while being delivered to each succeeding compartment. Shower pipes *M* are for the purpose of forcing all unscreened residue out of the rotating drum into the compounding box and keeping plates *I* clean.

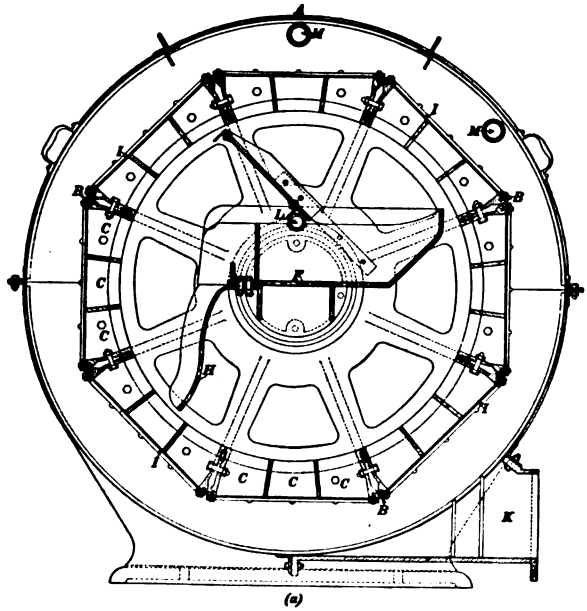

FIG. 14.

The drum is the only moving part of the machine; it rotates in bearings outside of the machine; there are no packings, cams, or springs. The speed is 25 r.p.m., and about 1 h.p. is required to operate it. The screen-plate area is approximately 70 sq. ft., and the perforations are holes of .1 in. diameter and 42 holes per sq. in.

QUESTIONS

(1) Name the principal points to be considered in selecting a screen.

(2) Explain the effect on the capacity of a rotary screen of (*a*) increase in consistency, (*b*) increase in speed of impeller.

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(3) What is the effect of increases as above on the (*a*) power consumption; (*b*) amount of tailings?

(4) Mention some of the difficulties to be met in operating the screen room.

(5) Distinguish between inward flow and outward-flow screens; illustrate your answer by a sketch.

TREATMENT OF PULP AFTER SCREENING

SLUSHING OR DECKERING

48. Thickening or Concentrating Stock.—The consistency of screened stock is from 0.25% to 0.6%; the process by which some of the water is removed and the consistency increased so that the stock contains from 3% to 6% of air-dry fiber is called **slushing, deckering, de-watering,** or **concentrating.** This practice is common wherever a paper mill using the stock is sufficiently close to the pulp mill to allow the stock thus concentrated to be moved economically by means of piping or a special conveyor. This is the cheapest form in which stock may leave a pulp mill as a finished product, and it is the most economical form for an adjacent paper mill to receive it as its own raw material. The other forms in which screened stock may leave the pulp mill are fully described later.

The usual apparatus employed to effect the thickening consists of a cylindrical frame, covered with a fine-mesh wire screen, revolving in a vat that contains the thin stock, just as it comes from the screens. The stock remains on the wire cloth, while the water runs through into the inside of the cylinder, and then out through a suitable connection in the ends of the cylinder. The stock is removed in various ways, to be described later. The water removed is approximately the same in amount as was originally added to the stock coming from storage tank or grinder pit for screening. From the consistency table at the end of this Section, assuming the consistency of the stock to the decker as 0.35% and discharge as 4½%, over 60,000 gallons of water are removed for each ton of air-dry fiber. The greater part of the water thus removed is usually returned, to be used over again in thinning up fresh stock for screening purposes, the excess, if any, being passed through a save-all for the removal of such fine fibers as it may contain. This rejected liquid is called **re-water** or **white water,** the latter being the more common term.

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The apparatus used in slushing is called a **decker.** The capacity of deckers operating on any kind of stock varies with the length of face of cylinder, mesh of cylinder cover, speed of rotation, and, slightly, with the diameter of the cylinder; it is also affected by the consistency of the stock. The capacity on slow[1] or short-fibered stock, as groundwood, is much less than on free[2] or long-fibered chemical pulp. Under ordinary conditions, a decker may have a daily capacity of 1.25 tons per linear foot of cylinder face on groundwood and from 4 to 5 tons on chemical pulps.

The wire covering is usually from 30 to 65 mesh, the former being the coarsest used for chemical stock.

49. Decker, or Thickener.—In Fig. 15, (*a*) is a plan and (*b*) a sectional elevation of a decker, or thickener; (*c*) is an end view, drawn to a much smaller scale. The various parts are numbered as follows: 1, doctor (upper); 2, couch roll; 3, doctor (lower); 4, screen cylinder; 5, partition between vat and thickened pulp outlet; 6, white-water outlet; 7, pulp inlet; 8, vat; 9, bearings; 10, pulp outlet; 11, baffle; 12, adjustable springs for regulating pressure of couch roll 2 on cylinder 4; 13, false bottom.

The principles involved in the operation of this machine are widely used in pulp and paper machinery; they are found in wet machines of various types, deckers and thickeners of different types, save-alls, and paper machines. The object of the decker is to remove a certain proportion of the water from the pulp supplied to it, thus increasing the consistency and thickening the pulp.

Stock is admitted through inlet pipe 7 and is distributed along the full width of the vat 8 by the baffle 11. The stock level in the vat is maintained from 3 in. to 6 in. below the top of the cylinder, or even lower if the cylinder is rotating fast. The water flows into the cylinder through the wire mesh that covers it, and then flows out at the end of the cylinder through outlet 6. This water, called white water, may be discharged at both ends of the cylinder, when proper arrangements are made in the cylinder, and this is the usual practice where large amounts of water are handled, especially in thickening chemical pulps.

The space between each end of the cylinder and the vat ends is sealed by a felt collar, thereby keeping the stock from leaking

[1] Called "slow" because water drains from it slowly.

[2] Called "free" because water drains from it freely.

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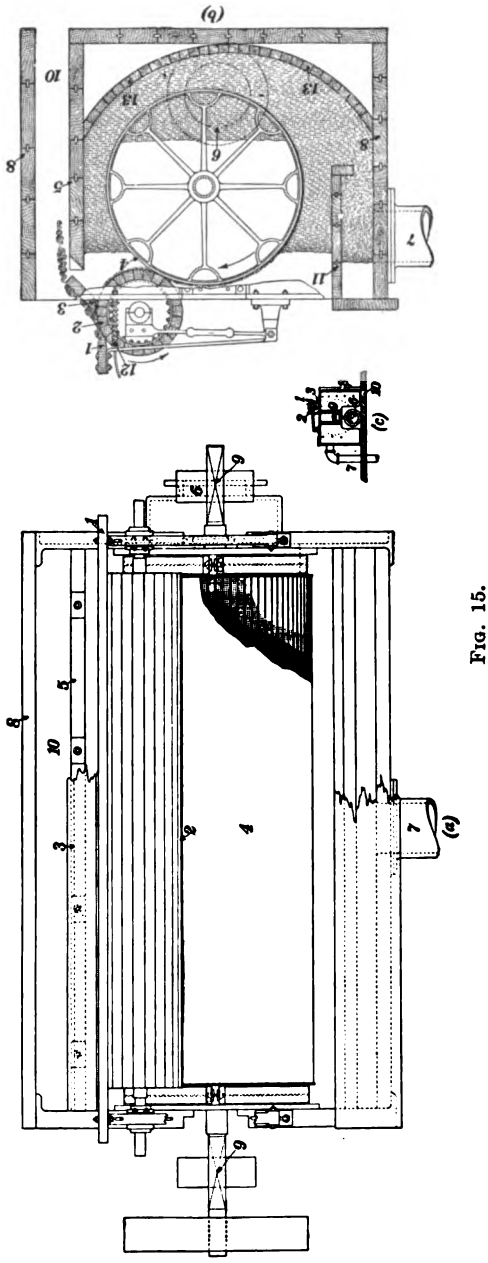

FIG. 15.

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into the white-water outlet. There are various types of collars used, but all serve the same purpose; their adjustments should be frequently checked, as it is very important that no leaks occur at this point. The level of the water inside the cylinder is generally kept as low as possible; if a free discharge is provided, this water level will be automatically regulated. The difference of level between the stock in the vat and the white water in the cylinder greatly influences the amount of stock caught on the surface of the cylinder. If there were no difference of level, no stock would be deposited on the cylinder, and the greater the difference in level the greater the head inducing the flow of water and the greater will be the amount of stock deposited on the cylinder. The amount of stock deposited on the cylinder is also greater as the vat level is increased, *i.e.*, as the area immersed is increased, but the consistency of the thickened stock will be less, if the difference in level falls. In practice, both the difference in level and the area immersed are kept as high as possible.

The couch roll 2 bears throughout its entire length on the surface of the cylinder, and because of its weight, it squeezes some water from the film of stock as it passes between the roll and the cylinder. This stock adheres to the surface of the couch roll, and as the latter turns, is scraped off by the doctor 1, falls to doctor 3, and thence into the outlet 10.

Couch rolls are of varying design; but all are covered with some soft and yielding material (such as wool felt) that is wound around them in a sheet or else by a special felt covering that is so constructed that the successive rows of narrow felt strips set on edge give the necessary resiliency. A couch roll that is said to give good results is made by nailing small sponges to a wood roll.

The vat shown in the figure is of wood throughout, but modern practice is inclined to the use of all steel vats, of concrete, or with metal ends and wood sides. The purpose of the rounded false bottom 13 is to prevent the settling of stock in corners and to facilitate cleaning. All vats should be supplied with a wash-out valve in the bottom (not shown in the cut). The couch roll is caused to rotate by its contact (friction) with the cylinder (sometimes called the cylinder mold) on which it rests, and the arms shown in the cut keep the roll in alinement and adjustment. The purpose of the springs 12 is to adjust the pressure of the couch roll, in case its weight is excessive.

The cylinder is made up of spiders, which are mounted on a

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steel shaft. Around the periphery of the spiders are secured round rods, extending lengthwise of the cylinder, upon which, one or more layers of wire cloth are fastened. The spiders and rods are made of brass (or bronze for sulphite pulp), and the wire cloth is of the same material. There are various details in design, which should be carefully specified, depending on the kind of stock to be treated and the standard of quality of equipment desired by the purchaser.

The wire-cloth covering should be cleaned periodically by a high-pressure water jet or, better, by a steam jet, to insure that the decker operates at its highest capacity.

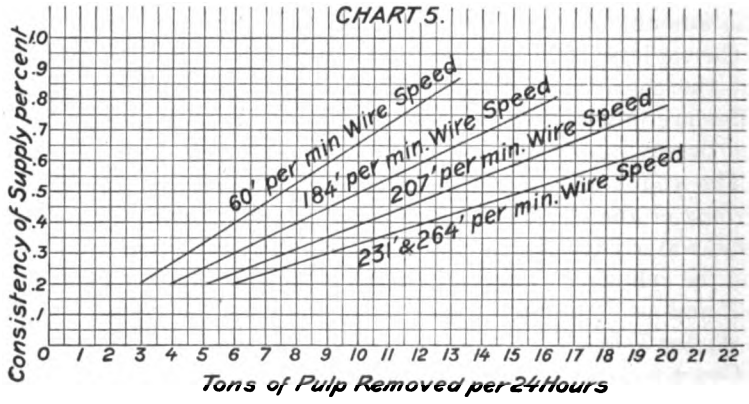
CHART 5.
Consistency of Supply percent
60' per min Wire Speed
184' per min. Wire Speed
207' per min. Wire Speed
231' & 264' per min. Wire Speed
Tons of Pulp Removed per 24 Hours

The consistency of the stock supply, the speed of the cylinder, (and mesh of cylinder cover) are very important factors in determining the capacity; if the machine be operated properly, these are the only factors. Charts 5 and 6 indicate the capacity that may be expected from a decker having a cylinder 36 in. in diameter and 94 in. long when operating on groundwood, and show the effect of varying speed of mold and consistency of stock in the vat. No equivalent data concerning chemical pulps is available, but it is safe to expect a machine operating on chemical pulps to have a capacity that is three to four times as great as the chart shows for groundwood.

Chart No. 5 shows the effect on the capacity of a decker, when the consistency of supply is altered at various speeds of the cylinder; and the curves on this chart also show what capacity may be expected from groundwood pulp, if the consistency of supply and speed of the cylinder are known. In this case the

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cylinder was 94 in. long; so the capacity may readily be calculated in terms of tons per inch of cylinder width per day. As an example, assume that the supply has a consistency of 0.5%. Following this horizontal line, it is found that if the cylinder is rotating with a surface speed of 160 feet per minute, the capacity of the decker will be 7.6 tons per 24 hours; whereas at 207 feet per minute, the capacity will be 12.9 tons per 24 hours. On the other hand, if the consistency be increased to 0.7%, the capacity at 160 feet will be 10.7 tons per day. The slope of the curve therefore shows also that at the higher speeds an increase in consistency gives a correspondingly greater increase in capacity than at the lower speeds.

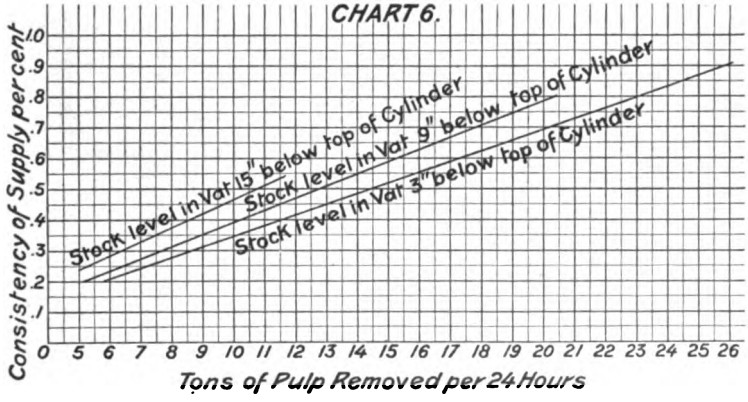
CHART 6.
Consistency of Supply per cent
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Stock level in Vat 15" below top of Cylinder
Stock level in Vat 9" below top of Cylinder
Stock level in Vat 3" below top of Cylinder
0 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26
Tons of Pulp Removed per 24 Hours

Chart No. 6 shows the effect on the same machine of changing the distance of the stock level in the vat below the top of the cylinder. The wire speed in this case was kept constant at 207 feet per minute. With a consistency of 0.5% a 15-inch difference in stock level gave a capacity of only 10.9 tons while the 9-inch level gave 12.8 tons, and the 3-inch level, 14.5 tons. In other words, the larger the area of the cylinder immersed in the stock the greater is the capacity of the machine. It is thus evident that a careful test should be made to determine the best operating conditions for each grade of stock.

The consistency of stock delivered decreases as the level in the vat rises. In practice the level is maintained as high as possible to give the required consistency of discharge.

50. Pneumatic Thickener or Save-all.—Fig. 16 shows three views and one detail view of a pneumatic thickener, which is also

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used as a *save-all* and as a water filter. A partial end view is shown at (*a*), a side view at (*b*), and a plan at (*c*). The numbers refer to the following details or parts: 1, air pump; 2, hand wheels

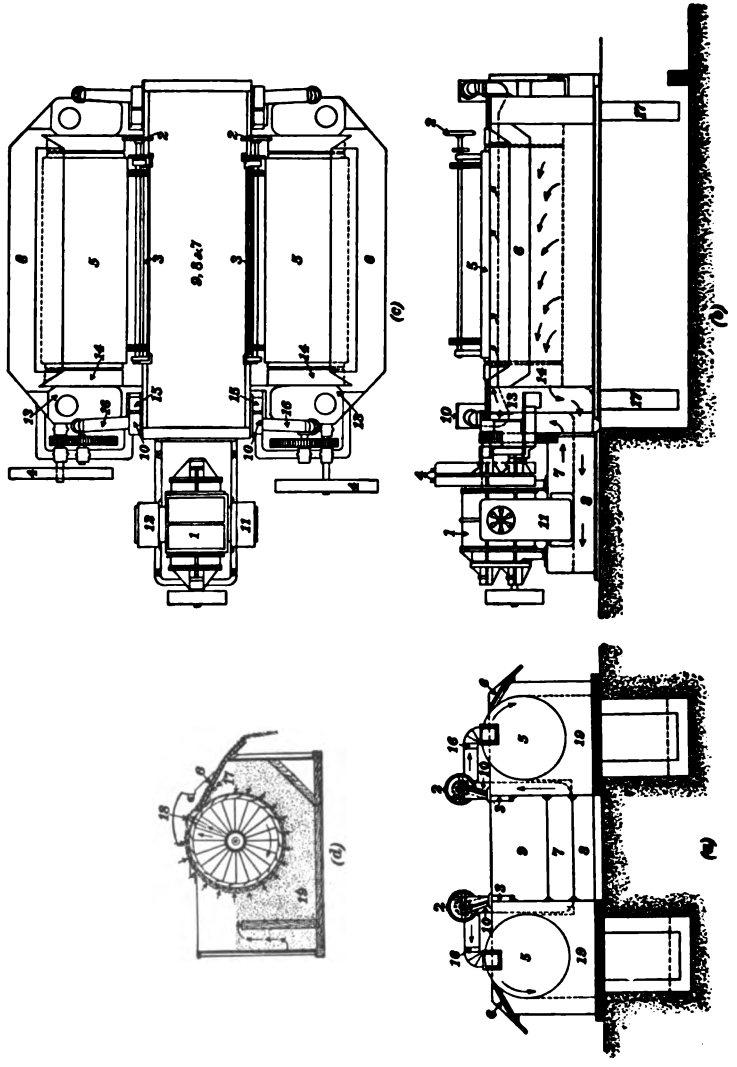

FIG. 16.

for stock-inlet gate; 3, stock-inlet gate; 4, drive pulleys for cylinders; 5, cylinders; 6, doctor; 7, pressure, or blower, chamber; 8, vacuum, or suction, chamber; 9, pulp supply; 10 and 11, parts

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of blower duct; 12, 13, 14, 15, parts of vacuum duct; 16, blower duct; 17, shower (water); 18, point where stock is blown off cylinder; 19, vat.

As a decker, this machine is used to thicken chemical stocks. The cut shows two cylinders 5, which revolve in opposite directions in a vat 19, the cylinders being covered with the usual wire cloth. The stock enters the vat over adjustable gates 3, which are operated by the hand wheels 2; the gates are nearly as wide as the cylinder is long, thereby effecting an even distribution of the stock without objectionable eddies. The fibers are deposited on the surface of the cylinders, as the result of the water passing through the wire-cloth covering. Instead of relying on a difference of level between the stock on the outside and the water on the inside of the cylinder to force the water through the wire cloth, as in the machine shown in Fig. 15, a difference of air pressure is created for this purpose. Each cylinder is divided into radial sections (sectors) that run the full length of the cylinder; see view (*d*), which shows an end view of the cylinder. The ends of each section are open, to provide an exit for the water that flows through the wire cloth into the pockets formed by the sections. As the cylinders revolve, the ends of each pocket pass by openings or ports in a duct in which a partial vacuum is maintained. The suction action thus induced in the pocket causes the water to flow through the wire cloth into the pocket, which it leaves by the ends. In this way, a film of stock is formed on the surface of the cylinder. As each section of the cylinder (pocket) reaches the top of its revolution, the ends again register with another opening or port in a duct in which air is maintained under pressure, and which lifts the sheet of pulp off the wire cloth, as shown at 18, view (*d*), whence it falls on the doctor 6 and then slides off into the tank or conveyor that is provided to receive it. A water shower 17 cleans the covering, and the operation of forming and discharging the sheet continues. On account of this alternating suction and blowing (which is due to the action of the air pump 1) and the length of time for the water to leave each pocket, the peripheral speed of the cylinder is much less than in other types of thickeners, a fair speed being 50 to 60 ft. per min. If the diameter of the cylinder is, say, 36 in., the number of revolutions per minute is thus about 5.3 to 6.4 r.p.m.

The machines may be installed in single units or in batteries of

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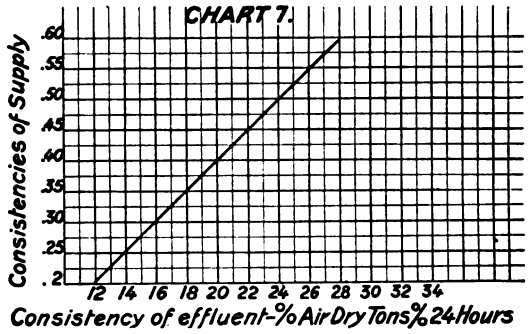
two or more machines, bolted together, in which case, the arrangement of pressure and vacuum piping is varied accordingly. Different types of pressure and vacuum pumps are used, but the rotary type is the standard. The capacity of these machines is subject to the same general laws that govern the operation of couch-roll deckers. When operating on sulphite stock, 3.5 tons per lineal foot per 24 hours is a fair estimate of the capacity of the pneumatic thickener.

Chart No. 7, which is a record of actual tests, indicates the capacity at various consistencies of supply. The general effect of a change in consistency of the stock furnished to a pneumatic sulphite-pulp thickener may be judged from this chart. The



pulp was quick-cook sulphite, the cylinder was 74 inches wide, covered with 50-mesh wire, and traveled at a surface speed of 62 feet per minute. By changing the consistency from 0.2% to 0.6%, Chart 7, the capacity in tons of air-dry pulp for 24 hours is seen to have increased from 12 to 28 or, in terms of tons per foot of cylinder length, the corresponding capacities were 1.95 tons and 4.51 tons. The capacity at any intermediate consistency as, for instance, 0.4%, is found by extending the horizontal line at that figure until it strikes the curve and then following the perpendicular to the corresponding capacity figure which is here found to be 20 tons per 24 hours. Conversely, if it is desired to determine the consistency of supply that would give a capacity of 24 tons, follow the vertical line from 24 until it meets the curve, and then extend the horizontal to the consistency figure, which is found to be 0.5%. Many interesting points can be developed by the use of graphic charts.

These machines require but very little labor to operate. The

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cylinder facings need an occasional blowing out with the steam hose. One man can attend to practically any number of machines required by an individual mill. The consistency of the stock delivered by the machine varies slightly with a varying consistency of supply, and may be altered somewhat by varying the amount of suction. Stock from 3% to 5% air dry is obtained from these machines.

51. The Water Extractor.—In Fig. 17, is shown a pulp thickener that differs materially from the couch-roll decker and pneumatic thickener previously described. The cut shows a plan (*a*) and an end view (*b*). The details or parts are numbered as follows: 1, cylinder; 2, paddles; 3, butterfly valve; 4, float; 5, vat; 6, shower; 7, thickened-pulp chamber; 8, agitator; 9, white-water box; 10, thickened-stock outlet; 11, nut on butterfly valve; 12, baffle.

This machine operates under the same general principles as the decker described in connection with Fig. 15. The main differences are in the construction of the cylinder, absence of couch roll, and the way in which the thickened stock is delivered. In fact, it might perhaps be more appropriately called a *water extractor*, from the fact that as the pulp flows through the vat, the cylinder provides a means for the water to drain off, thereby leaving the remaining, or discharged, stock thicker. The cylinder consists of several spiders, mounted on a steel shaft. Around the circumference of these spiders, are bolted hard-wood slats 2, set at an angle, as shown in the cut. Over these is stretched a layer of heavy copper-wire cloth, about $\frac{1}{4}$-inch mesh, which forms the support for the outer layer of fine mesh (30 to 50) wire cloth. A better support consists in winding around the slats a continuous copper wire, of about 14 gauge and about $\frac{1}{2}$ inch center to center, upon which the usual 15-mesh and 30-mesh wire cloth covers are secured.

The stock to be thickened enters by the butterfly valve 3. This valve is controlled by a float 4, which is set so as to keep the stock in the vat at a certain level. The cylinder revolves in the vat 5 in the direction indicated by the arrow, and the ends are sealed so the stock cannot run into the cylinder by way of the ends, which are connected with the white-water box 9. The water in the stock flows through the fine-mesh wire on the surface of the cylinder to the inside of the cylinder, and then flows out at the ends to the white-water box; this leaves the fiber on the

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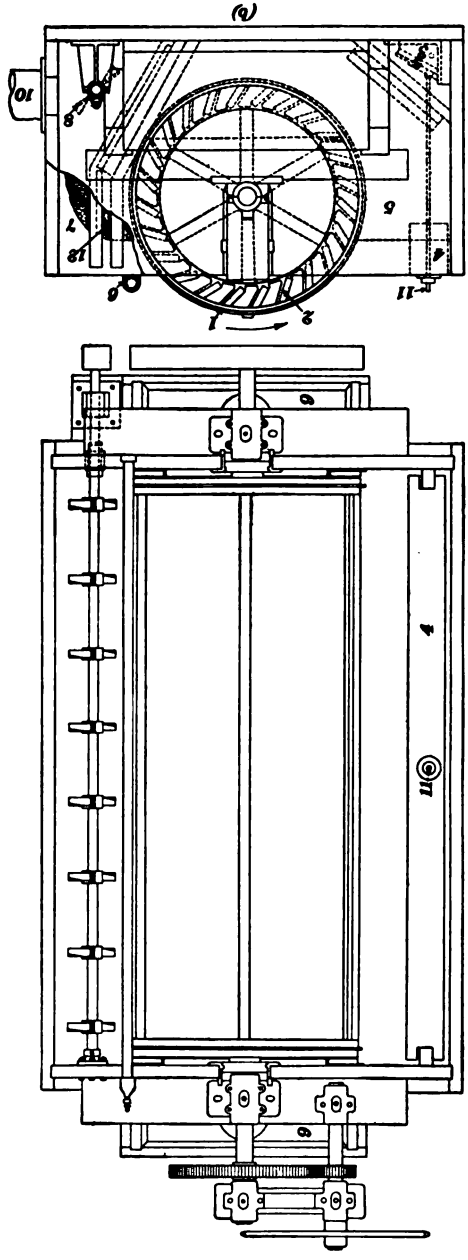

FIG. 17.

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surface of the cylinder, and it is carried along on the cylinder to the point where the shower 6 strikes it. The shower acts as a doctor, and it washes the thickened stock into thickened-pulp chamber 7. The baffle 12 divides the vat proper from the thickened-pulp chamber. The agitator 8 insures a thorough mixing of the stock, and it breaks up any fiber bunches or nodules. The pulp leaves by means of the discharge pipe 10.

This machine is designed for continuous operation. The white water should be inspected to determine the amount of fiber in it, and an excess of good fiber indicates broken cylinder facings. This machine is also used as a slush machine for chemical pulps, water filter, and save-all.

REGULATION OF CONSISTENCY

52. Necessity for Regulating Consistency.—The success of paper manufacturing processes depends very largely upon the maintenance of uniform conditions of operation, and this makes it necessary to consider how a definite volume of slush stock may be so regulated that it will contain a certain definite percentage of dry fiber. No thickening apparatus is able to deliver stock of such regular consistency as to be within the limits of the desired degree of accuracy. The usual method, therefore, is to be sure that the stock leaving the thickeners is dryer than is required, so that a small amount of water may be added to thin the mass to the *predetermined standard. The law of friction is the basic principle underlying most regulating schemes.* The application of the principle is made in several ways, only one of which will here be explained.

53. The Regulator.—The stock from the slush machines (deckers or concentrators) is collected in a tank or chest, where it is kept in a state of constant agitation. A fairly large tank is advisable, so that the fluctuations of consistency will be as small as possible. The stock should preferably be pumped from this tank to another tank, and the necessary amount of water should be added while the stock is in transit. A stock regulator is shown in Fig. 18, and the various parts are lettered as follows: *A*, white-water supply; *B*, screw attached to outlet; *C*, ratchet; *D*, pawl; *E*, link; *F*, shaft; *G*, upper chamber; *H*, lower chamber; *I*, overflow to decker chest; *J*, scale beam; *K*, counterweight; *L*, stock supply from decker chest; *M*, orifice from constant-head

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box to weighing chamber; *N*, constant-head box; *O*, pipe leading to weighing chamber; *P*, knife-edge bearings; *R*, reducing elbow; *S*, friction outlet pipe; *T*, pulley on shaft driving pawl eccentric.

Stock enters the constant-head box *N*, in the bottom of which is a round orifice *M* in a brass plate. A constant head is maintained by admitting through pipe *L* more stock than can pass through the orifice *M*, the excess overflowing the baffle into pipe *I*, which conducts it back to the decker chest. That part of the stock that flows through orifice *M* passes through pipe *O* into the variable level chamber *H*, which is mounted on a scale beam *J* that balances on knife-edge bearings at *P*. The counterweight *K* may be moved along the other arm of the beam as in any weighing machine, and is used to balance *H*, which is partially filled with stock.

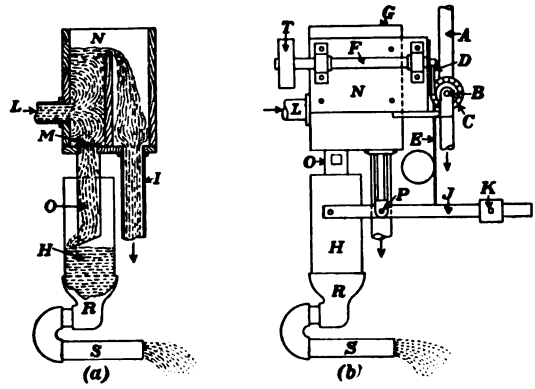

FIG. 18.

Now it is a well-known fact that the friction of stock flowing in pipes varies in accordance with *changes in consistency;* also, if a relatively constant volume of stock is to pass through a pipe of given size, it will require a greater head (or pressure) to maintain the same flow when the consistency of the stock is increased. This fact is made use of in the following manner:

Through a small by-pass, taken off from the main stock pipe, as close as convenient to the stock pump, sufficient stock is continuously drawn to maintain an overflow in the head box *N* of the regulator, thus maintaining a constant head on the orifice *M* and producing a constant flow in the pipe *O*. Since this orifice offers a minimum of frictional resistance to the passage of the stock, the amount discharged through it to the variable level

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chamber *H* beneath it, will vary but little with changes in consistency. In passing through the variable level chamber *H*, however, the stock meets with considerable frictional resistance, which is governed by the reducing elbow *R* and by the size and length of the outlet pipe *S*, with the result that the level in *H* rises a sufficient amount to overcome the resistance of the reducing elbow *R* and pipe *S* and maintain the flow. Thus, when the consistency of the stock increases, the level in chamber *H* rises; and when the consistency decreases, the level in chamber *H* falls.

A water-supply pipe *A* is connected to the inlet of the stock pump (which supplies stock to be regulated) by means of a gate valve, the stem of which is connected to a screw *B* passing through a double-faced ratchet wheel *C*. A pawl *D* is provided for rotating the ratchet wheel in either direction; a set of links *E* connects the scale beam *J* of the regulator and the pawl; a shaft *F* connects with an eccentric for operating the pawl; and a safety stop disengages the pawl when the valve is wide open or shut.

The outlet pipe *S* from the weighing chamber *H* is made of the proper length for the consistency desired; the stock will then occupy a certain volume and be at a certain definite level in chamber *H*. So long as the consistency is not altered, this volume remains constant, and the weight of the stock in chamber *H* remains constant also. The counterweight *K* is set to balance the weight of the chamber *H* and its contents, and the links *E* are then adjusted so the pawl *D* will not engage with either side of the ratchet. If the consistency of the stock increases, the additional frictional resistances will cause the stock to back up in chamber *H*, increasing the weight of the stock in the chamber (since the level of the stock in the chamber rises); this brings down that end of the scale beam to which chamber *H* is attached and causes the other end, with the counterweight, to rise; this movement is transmitted by the links *E*, which causes the pawl *D* to engage with the ratchet wheel *C* and rotates the ratchet wheel. Since the ratchet wheel cannot move sideways, it will cause the screw *B* (which works in it as in a nut) to back out and open the valve until sufficient water is added at the pump to reduce the total volume of stock passing through the pump to the proper consistency. When this occurs, the scale beam again becomes horizontal, the pawl comes to neutral position, engaging neither side of the ratchet, and the water valve remains open the

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necessary amount. If, now, the stock becomes too thin and less water is required, an opposite movement (due to the same causes as just described) will close the valve the necessary amount. As previously mentioned, a safety stop disengages the pawl when the ends of the valve travel are reached.

If sufficient care be taken to insure proper operating conditions, stock can be controlled with this apparatus with a maximum variation of 5% over and under the desired consistency.

EXAMPLES

(1) What other terms are applied to the process of removing water from pulp? What is the purpose of this operation?

(2) In concentrating pulp from a consistency of 0.7% to 4.2% how many tons of water will be removed by a decker handling 12 tons of air-dry pulp per day? *Ans.* 1428 tons.

(3) If the capacity of a pulp thickener 74 in. long is 24 tons in 24 hours, how much pulp will an 84-in. machine handle? *Ans.* 27.24 tons.

(4) What is the difference in cubic feet of stock passed per hour between a decker-supply pump handling stock at .5% consistency and the thick-stock pump handling pulp at 3.5% consistency at the rate of 18 tons per 24 hours? *Ans.* 4115 cu. ft.

LAPPING

54. Object of Lapping.—In order to convert both mechanical and chemical stock into a form suitable for transportation or for storage purposes, it is necessary to extract water from screened stock and collect the fibers into sheets dry enough to hold together and enable them to be folded or lapped into a bundle. The process by which this result is accomplished is called **lapping,** and the bundle thus obtained is called a **lap.**

The lap contains from 30% to 45%, by weight, of air-dry fiber, depending upon the type of machine used to extract the water. Such machines, usually called **wet presses,** are all the same in principle; they make use of a cylinder and vat, similar to that of the slush machine with couch roll, and which was previously described. They differ, however, in the arrangement of the part which presses the water from the sheet formed on the cylinder. An endless woolen felt picks up the sheet from the cylinder and runs between one or more pairs of squeeze rolls, which press the water out, and the pulp may then be collected in sheets or bundles. This is a continuous process.

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55. A wet press is shown in Fig. 19, the various parts and details of which are numbered as follows:

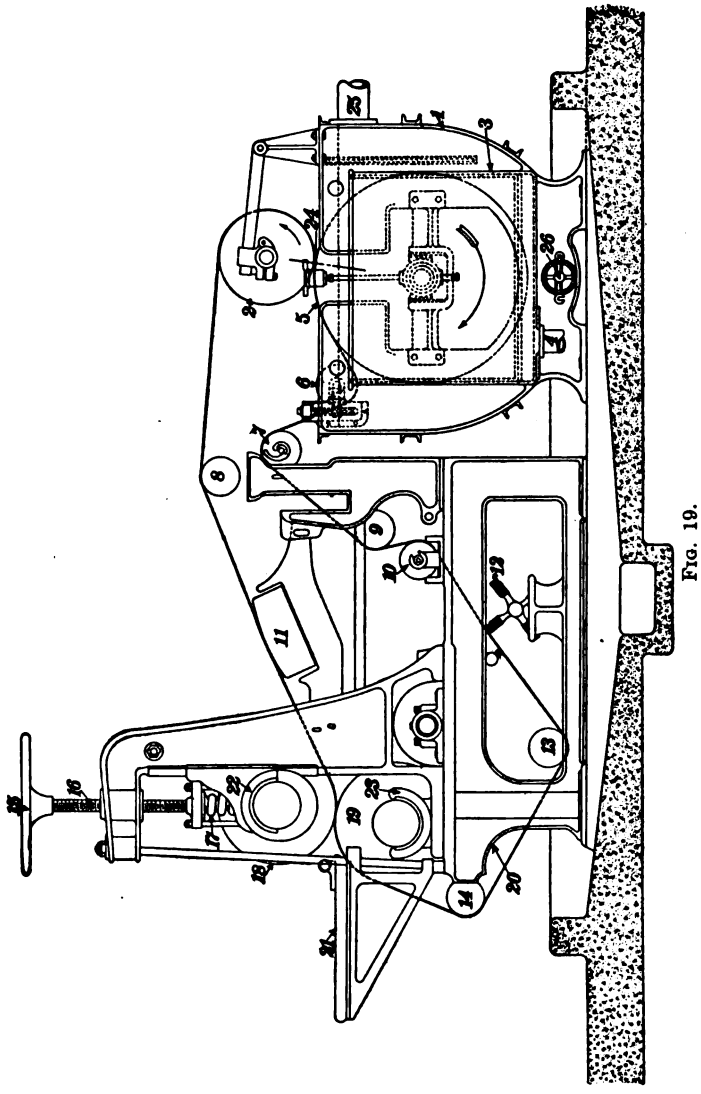

Fig. 19.

1, vat; 2, couch roll; 3, white-water discharge box from the cylinder; 4, white-water discharge pipe from cylinder; 5, cylinder; 6, 7, 8, felt rolls; 9, felt-roll—stretch roll; 10, felt roll—

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guide roll; 11, suction box; 12, whipper; 13, 14, felt rolls; 15, hand wheel; 16, screw; 17, spring; 18, top press roll; 19, bottom press roll; 20, stand; 21, pulp table; 22, top press-roll bearing; 23, bottom press-roll bearing; 24, line of pressure between couch roll and cylinder; 25, inlet for stock; 26, clean-out for vat.

The pulp sheet-forming part is essentially the same as that for the slush machine, or decker; but it carries the process farther, by pressing more water out and delivering the pulp in a sheet or bundle. An endless woolen felt passes between the couch roll 2 and the cylinder 5. The layer of pulp that has been collected on the surface of the cylinder is transferred to the felt by the pressure of the couch roll. The felt passes out, around the couch roll, over the felt roll 8, carrying on its outside surface the sheet of pulp. The pulp then passes over the suction box 11, where a little water is drawn out of the felt, so that when the main pair of press rolls 18 and 19 is reached, the sheet and felt will be dry enough to stand a very heavy pressure (comparatively speaking), which completes the pressing process. As the felt leaves this press, the sheet of pulp adheres to the surface of the top press roll 18 and continues to follow it around, thus causing the roll to be covered with successive layers, which are compacted into a homogeneous sheet. The operator removes this layer from the roll by cutting it with a sharp stick or by lowering a long steel knife, or "doctor blade," suspended over the roll. One make has a knife that lies in a recess in the press roll, which is pushed out (automatically, if desired) when the sheet (layer) is of the proper thickness. The sheet falls on the table 21, where it is folded (usually twice each way) into a bundle, or lap, and placed on a truck or conveyor as the finished product of the machine.

On leaving the press rolls, the felt continues over rolls 14, 13, 10, 9, 7, and 6, from which it is carried below the surface of the stock in the vat and comes into contact with the wet pulp on the surface of the cylinder before the couch roll is reached. This results in a gentle pressing effect on the sheet and allows some of the water that is pressed out at 24 to pass upward through the felt and to run down on the upper side of the felt and back into the vat, without destroying the formation of the wet sheet of pulp on the cylinder. It is not absolutely essential to use a roll as shown in position 6; the felt could pass directly from roll 7 to point 24, but the water pressed out would then have no oppor-

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tunity of getting away, except at each side of the felt, and experience has shown that more uniform sheets are obtained when the arrangement is as shown in Fig. 19. This is particularly true in the case of chemical pulp, as the sheet is so thick and carries so much water with it at this point.

56. The felt rolls are made of wood or are formed of steel pipe, which may be plain or galvanized. Care should be taken that they are kept smooth, and they may even be covered with copper or brass tubing, to prevent corrosion and ensure a smooth surface. The suction box 11 is made of metal or wood, with a perforated or slotted cover; it is connected by suitable piping to a suction pump, and from 5 inches to 10 inches of vacuum is maintained in it. The top press roll is made of either iron or wood, and the bottom roll is made of iron, often rubber covered. Pressure is applied to the top press roll either by springs (as shown) or by hydraulic cylinders, the former being the more common. Weighted levers, as on a paper machine, are also very frequently used.

The felt is cleaned while the machine is in operation by a shower of water and the whipper, as shown at 12; the revolving blades of the whipper come into contact with the water soaked felt, knock off particles of pulp that adhere to it, and keep the felt in proper condition to pick up the sheet again at 24.

57. The woolen felts used are of special construction; they are woven so as to allow water to pass freely through them and at the same time to secure durability. They weigh from .22 lb. to .26 lb. per sq. ft., and vary greatly in their length of service. The following figures afford an indication of what may be expected from an average quality felt as at present available: on groundwood, from 12 to 14 days; on chemical pulp, from 10 to 12 days.

When operating on groundwood, one operator can attend to two machines; but when operating on chemical pulp, an operator is required for each machine, on account of the greater capacity (larger output). If there are a number of machines, a sub-foreman is usually in charge; he attends to the flow of stock and to the adjustment of all valves.

An average figure for the capacity of a wet machine (wet press) in air-dry stock per 24 hours per foot of width of sheet is 1500 pounds for groundwood and 5500 pounds for chemical pulp.

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These figures represent ordinary working conditions, but they may be increased somewhat, under the most favorable conditions. The speed of the wet machines varies from 60 feet to 100 feet per minute, and is considerably less than the speed of the decker cylinders, on account of the necessity of forming a more uniform sheet.

58. Multi-Press Wet Machine.—This is another type of wet machine, but based upon the same general principle as that just described; it was designed to meet the demand for a machine, the product of which should test at least 45% air dry and be in convenient form for transportation. The main points of difference between this type and that described in connection with Fig. 19 are the number of pairs of press rolls and the form in which the finished pulp is delivered. The machine is shown in Fig. 20, and the various parts and details are numbered as follows:

1, vat; 2, cylinder; 3, couch roll; 4, bottom first felt; 5, baby press rolls; 6, first press roll, top; 7, first press roll, bottom; 8, second press roll, top; 9, second press roll, bottom; 10, bottom second felt; 11, pressure devices, baby presses; 12, tension breaking rolls; 13, top first felt; 14, top second felt; 15, pressure device, first press; 16 pressure device, second press; 17, device for raising first press; 18, device for raising second press; 19, guide rolls; 20, stretch rolls; 21, receiving table; 22, chain drive; 23, water jet; 24, white-water box; 25, stock inlet; 26, float valve; 27, felt whipper.

The pulp sheet is formed on the cylinder 2 and transferred to the felt in the same manner as described in connection with Fig. 19. After passing over roll 19, the felt, with the wet sheet on its upper surface, passes through three pairs of small, or baby, press rolls, where graduated pressures are effected by a system of levers and weights, so arranged as to subject the sheet to an increasing pressure as it passes through the several pairs of press rolls. A short top felt 13 is run around the baby press rolls and forms a cushion between them and the wet sheet; without this felt, the sheet would have a tendency to crush and to adhere to the face of the bare rolls. By the time the sheet reaches the *first press* rolls 6 and 7, however, it is dry enough to stand a heavy pressure without crushing, although the baby press felt is sometimes made long enough to extend through this first press and around the top roll. After passing this point, the sheet is led

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through a second pair of press rolls 8 and 9, called the *second press*, where more water is squeezed out. There is delivered at this point a continuous sheet, the width of the cylinder mold, which is prevented from following around the last top press roll (as in the machine of Fig. 19) by reason of its thickness and extreme dryness.

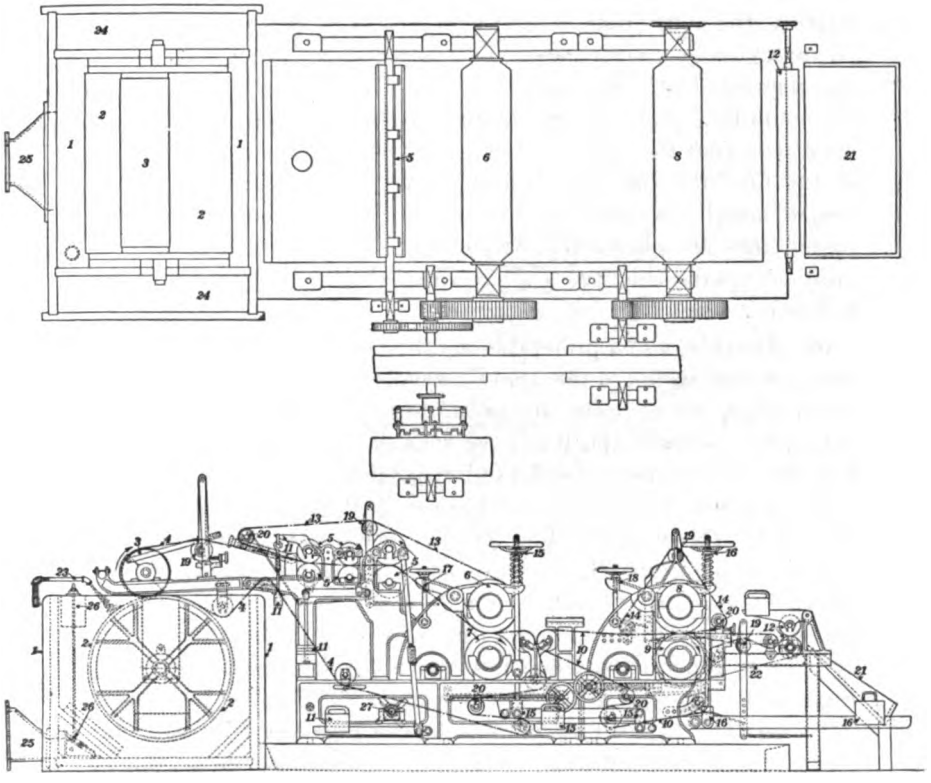

FIG. 20.

In order to form as thick a sheet as is possible, the consistency of the stock fed to the cylinder mold is greater than is usually obtained from the previous, or screening, process. A thickening machine is employed to take out some of the water, so that the consistency will be at least .6% to .7%. Any form of thickener may be used, but care must be taken to prevent lumpy stock, since such stock will not form well on the cylinder. The thickener is often so installed that the screened stock enters the

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thickener and gravitates to the vat of the wet machine, without the necessity of pumping.

The carrying felt 10 in front of the second press guides the sheet into a pair of squeeze or breaking rolls 12, which are running at a faster peripheral speed than the press rolls 8 and 9, with the result that the sheet is pulled apart across the machine and delivered to the table 21 in sheet form. In order to insure the pulling apart of the continuous sheet at regular intervals, the formation on the cylinder mold is partially prevented by filling with solder the openings in the wire cloth for about ½ inch wide clear across the cylinder. Few fibers are deposited along this line, as no water can pass through the wire cloth; but the fibers on each side of the line mat together sufficiently to make the sheet continuous, although very weak at this point. As many of these raised solder lines are placed on the surface of the cylinder as are required to make the sheets of the desired length; usually five are sufficient.

59. Another, and a preferable, method of converting a continuous web into sheets is the use of a revolving knife, having a saw-tooth edge, which cuts the pulp; Fig. 21 shows a press thus equipped. Here 8 and 9 are the rolls of the second press, as in Fig. 20. The bottom second felt drops immediately on passing a felt roll just behind the second press, and the sheet of pulp is guided by the slide 27 (Fig. 21) over the stationary knife 28. The revolving knife 29, driven by gears 30, just strikes the blade 28 and chops off the sheet, which is delivered by the (third) felt or apron 31 to the receiving tray 21. The pulp on the cylinder is generally divided into two strips by the water jet 23, Fig. 20, so that for each clip of the knife 29, Fig. 21, two sheets fall into the tray. This eliminates the breaking rolls and the solder lines on the cylinder, which give more or less trouble, due to the weakening of the web at so many points.

Power is applied to each bottom press roll of the multi-press wet machine, and the felts are made to turn all the other felt rolls. As a result, the felt cost is much higher on these machines than on the simple wet machines of the type shown in Fig. 19, since the felt does more work in the multi-press than in the simple wet machines and, hence, wears out faster.

The multi-press wet machine is never used on any other than chemical pulp, and the average production to be expected is approximately 4 tons per foot of width of sheet per 24 hours.

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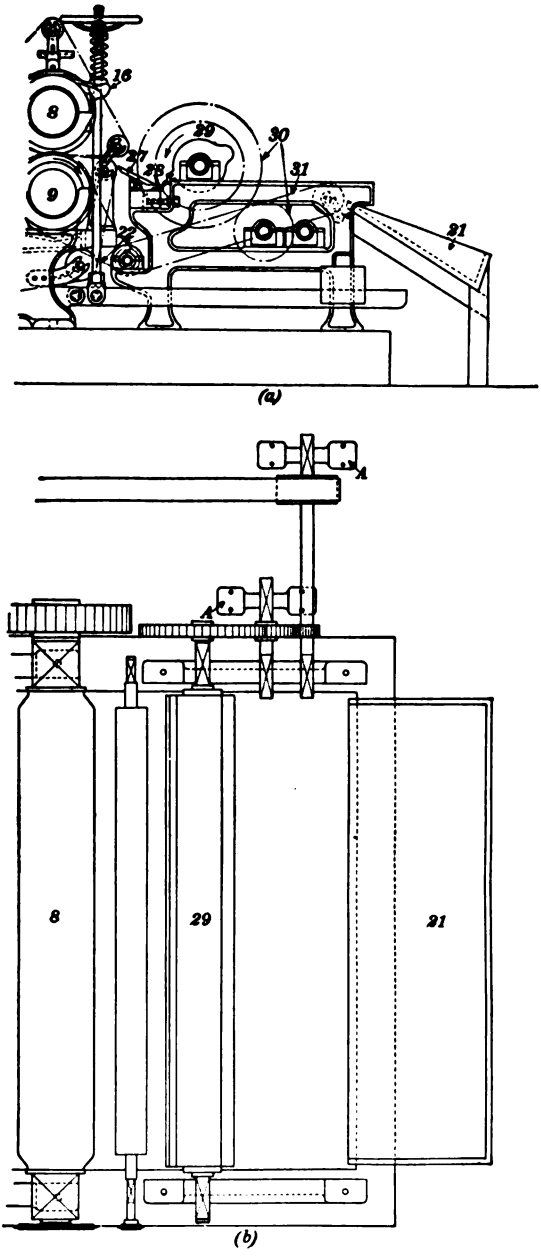

FIG. 21.

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One man is required to transfer the sheets from the table in front of the machine to the waiting truck or conveyor; it is usually necessary to have another man to watch the felts and attend to the thickening machine, which is employed in conjunction with the wet machine. In practice, the product tests about 45% air dry; but during some periods of the year and under certain conditions, the product may test slightly higher.

SAVE-ALLS

60. Object of Save-All.—The reclamation of stock (pulp fiber) from waste white water is one of the problems with which both the pulp maker and the paper maker have to deal; in fact, there is more waste through failure to solve this problem than is often realized. The most common method is to pass the surplus white water through a machine called a **save-all.**

One type of such a machine, the thickener of Fig. 16, has already been described; another is described below and illustrated in Fig. 22. Both of these machines operate by filtration through a metal wire cloth. A third machine, described below and illustrated in Fig. 23, differs from the first two machines in that filtration takes place through a woolen felt. On certain fine grades of stock, this latter machine is more efficient than those employing a wire screen, but its capacity is much smaller. Comparative tests of the felt-type save-alls and save-alls with 65-mesh wire-covered cylinder mold, about 3 feet in diameter, were made in a news-print mill. On groundwood white water, the latter type had five (5) times the capacity per foot of cylinder face as the former; but on another grade of white water, the latter type had only three (3) times the capacity of the former. The capacity of both types of save-alls materially increased when operating on white water from chemical pulps. The nature of, and the amount of, fiber in suspension affects the capacity to such an extent that no definite data can be given, as indicated by the following figures: the amount of white water handled by the felt type per foot of face of cylinder varied from 100 gal. to 20 gal. per min. The value and quantity of stock to be reclaimed, amount of white water to be treated, space taken up, and various other matters have to be considered before a decision can be made as to the machine best adapted to the conditions of a particular mill.

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The simplest type of save-all is built on the same principle as a contractor's gravel screen. It consists of a frame, inclined at an angle of about 70°; this is covered with wire screen. White water overflows a channel across the top and the water passes through the screen while little balls of fiber gather and roll off at the bottom. The more nearly horizontal the screen the faster will the water pass through, but this may be overdone to the point where the pulp fiber will not run off.

61. Wire-Cylinder Type of Save-All.—A save-all of the wire-cylinder type is shown in Fig. 22, and its operation is as follows:

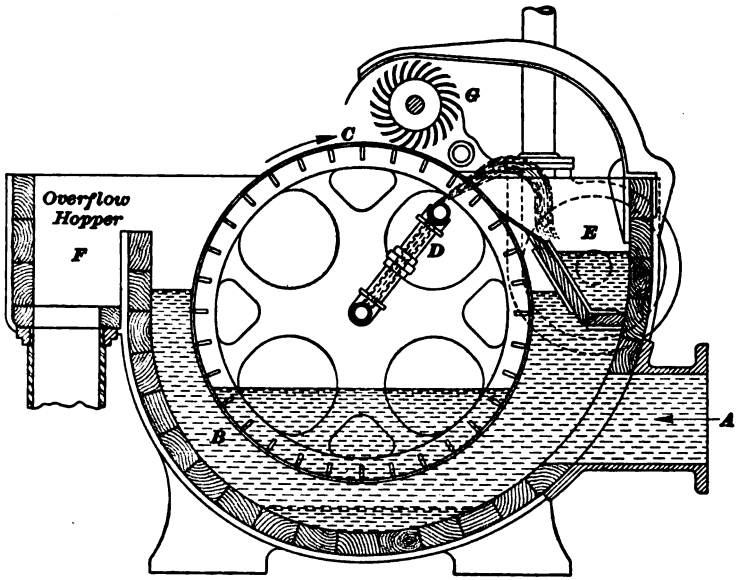

FIG. 22.

The white water enters the vat *B* through inlet *A*, and is strained through cylinder *C*, which is covered with a brass or bronze wire cloth, and which revolves in the direction indicated by the arrow. The water is discharged from that end of the cylinder that is opposite the drive. The fiber gathered on the mold is driven off by the shower *D*, as the cylinder revolves, and the recovered stock (a thick mixture of fiber and a part of the water from the shower) falls into stock compartment *E*, from which it is delivered to the point where it is fed to a centrifugal pump. When it is needed to help the shower in cleaning the wire, the

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brush *G* may be used. As brush *G* stands on adjustable brackets, it can be lifted off the wire, when not in action. If the volume of white water exceeds the capacity of the save-all, it overflows at *F*, which is connected to the main outlet of strained water from the cylinder.

The speed of the cylinder varies with the volume and consistency of the white water; it is controlled by a float, which rises and falls with changes in the head of water outside the cylinder. The float is connected with the variable speed drive.

62. Felt Type of Filter, or Save-All.—The felt type of save-all is a device for removing materials held in suspension in water. One important use of the machine in the paper industry is to remove valuable fiber from white water before allowing it to run to waste. A machine of this type is shown in Fig. 23, and the various parts are numbered as follows:

1, inlet pipe; 2, inlet box; 3, overflow pipe; 4, screw to regulate flow; 5, outlet for water from inside cylinder; 6, vat; 7, cylinder; 8, felt; 9, felt guide (automatic); 10, hitch roll; 10*a*, hitch roll, second position; 11, press rolls; 12, pan for water from press rolls; 13, drain pipe for pan 12; 14, stretch roll for felt; 15, tightening device for press rolls; 16 and 16*a*, hitch rolls; 17, hitch roll; 18, shower pipe; 19, whipper; 20, suction box; 21, squeeze rolls for felt; 22, doctor.

The water is admitted to the vat 6 in which revolves a polygonal drum 7, wound with brass wire and covered for five-sixths of its perimeter by a part of the endless felt 8. As the drum revolves in the direction indicated by the arrow, the felt travels with it. The water passes through the felt to the inside of the cylinder, on account of the difference in level between the water in the vat and that in the cylinder, leaving any fiber on the outside of the felt. The water, freed of the fiber, passes out of the cylinder by the outlet 5.

The felt, carrying the fiber on its upper surface, passes over several rolls, and after going over hitch roll 10, passes between the press rolls 11. The pressure of one press roll on the other is regulated by device 15.

The successful operation of the machine depends on the tendency of the fiber to stick to the upper press roll 11; as the fiber follows this roll, it is scraped off into a suitable receptacle by the doctor 22. The water that is squeezed from the felt and fiber in the press is caught in pan 12, and is returned to the vat by

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pipe 13. The felt now passes over the stretch roll 14 and hitch rolls 16 and 17. Showers 18 and whipper 19 serve to clean the

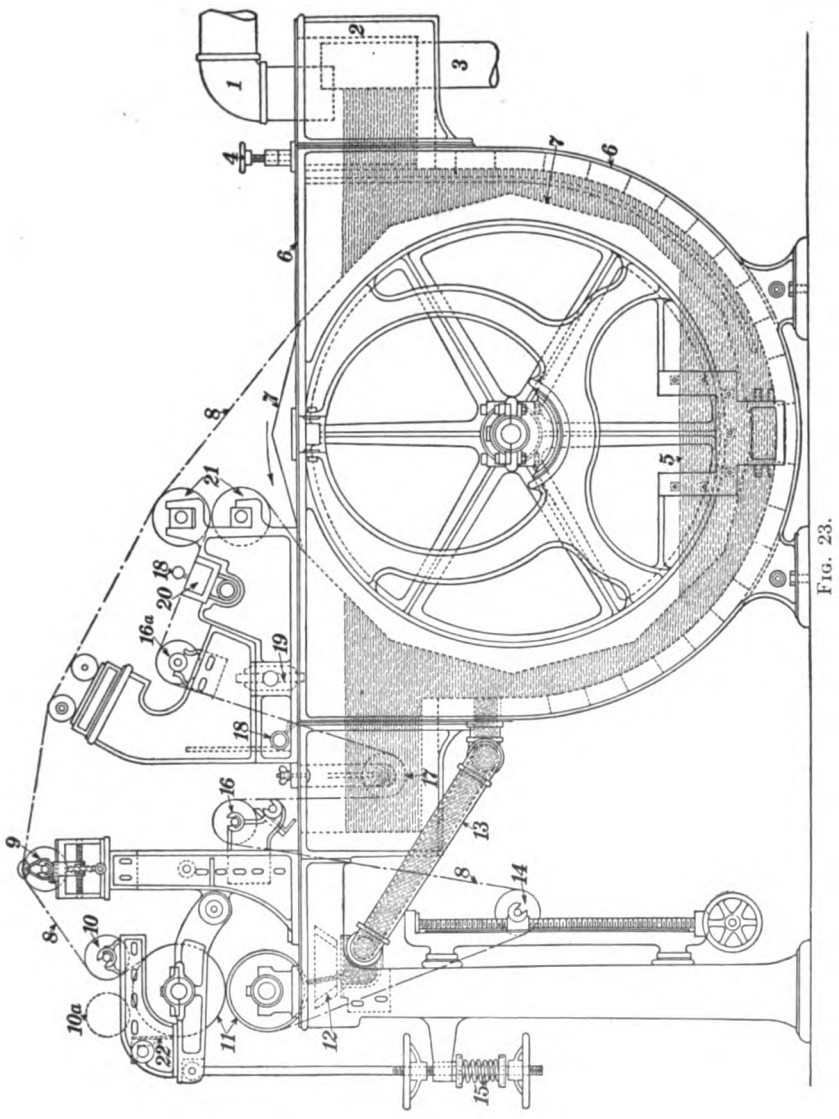

FIG. 23.

felt; and after passing over hitch roll 16*a*, a suction box 20, and through squeeze rolls 21, the felt reaches the drum and vat

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again. The power required to drive the machine at a felt speed of 12 ft. per min. is about 3 h.p.

This save-all needs more attention than the wire-covered cylinder type, but it is very efficient in the removal of all kinds of fiber from white water.

63. Settling Tanks.—Settling tanks, into which all white water is allowed to flow, are often used in conjunction with save-alls. Such tanks are so arranged that by means of baffles a majority of the fibers settle to the bottom, from whence they are removed by a pump that is connected to the bottom of the tank. This rich white water is used either for thinning purposes or is sent to save-alls. They work on the principle that by obstructing or diminishing the flow of the liquid, the fibers contained in it will sink to the bottom more readily.

HYDRAULIC PRESSING

64. Advantages of Hydraulic Pressing.—For the purpose of shipping pulp over long distances, the water content of the laps, or sheets, must be still further reduced, for which reason, they are often subjected to an additional process for removing water and to obtain a product containing from 50% to 60% air-dry fiber. A machine commonly employed for this purpose is a hydrostatic (usually called hydraulic) press. In operation, the laps, or sheets, are piled on a special truck; between each layer of laps is placed either a woven wire mat or one made of fiber, such as cocoa matting. The truck is then run into the hydraulic press, the whole mass being subjected to pressure that is often as high as 3000 lb. per sq. in. The mats are used between each layer of laps, so a uniform pressing effect may be secured. The water from the center of the laps is conducted to the outside, and is then allowed to escape during the pressing process, following the strands of the mat, which are practically incompressible.

The extra cost incurred by this operation depends upon the type of apparatus used and upon other conditions (cost of labor, power, etc.) at the individual mills, but may be placed at the present time as $2.00 to $3.00 per ton of air-dry fiber pressed. Since the only reason for this extra expenditure is to save on freight bills, there will evidently be some freight rate at which it will no longer pay to subject the pulp to the pressing process; this rate may easily be determined with the aid of the accompany-

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FREIGHT COSTS AT 20¢ PER TON, AND WEIGHTS OF AIR-DRY FIBER PER TON

Consistency (per cent)	Freight cost per ton of wet fiber (cents)	Cost per ton of air-dry fiber (cents)	Weight of air-dry fiber per ton of wet fiber (pounds)	Tons of wet fiber to yield one ton of air-dry fiber
34	20	59.8	680	2.94
35	20	57.1	700	2.86
36	20	55.6	720	2.78
37	20	54.0	740	2.70
38	20	52.7	760	2.63
39	20	51.3	780	2.56
40	20	50.0	800	2.50
41	20	48.8	820	2.44
42	20	47.6	840	2.38
43	20	46.5	860	2.32
44	20	45.4	880	2.27
45	20	44.4	900	2.22
46	20	43.5	920	2.17
47	20	42.6	940	2.13
48	20	41.7	960	2.08
49	20	40.8	980	2.04
50	20	40.0	1000	2.00
51	20	39.2	1020	1.96
52	20	38.5	1040	1.92
53	20	37.7	1060	1.89
54	20	37.0	1080	1.85
55	20	36.4	1100	1.82
56	20	35.7	1120	1.79
57	20	35.1	1140	1.75
58	20	34.5	1160	1.72
59	20	33.9	1180	1.70
60	20	33.3	1200	1.67
65	20	30.8	1300	1.54
70	20	28.6	1400	1.43
75	20	26.7	1500	1.33
80	20	25.0	1600	1.25
85	20	23.5	1700	1.18
90	20	22.2	1800	1.11
95	20	21.1	1900	1.05
100	20	20.0	2000	1.00

ing table. The first column gives the consistency of the pulp expressed as a per cent; the second column gives the cost per ton of freight at a rate of 20 cents per ton, which equals 1 cent per

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hundred pounds; the last column gives the number of tons of wet pulp required to produce 1 ton of air-dry pulp, the numbers in this column being the reciprocals of the consistencies expressed decimally (thus, $\frac{1}{.34} = 2.94$, $\frac{1}{.40} = 2.50$); the third column gives the freight cost per ton of air-dry fiber, found by multiplying the numbers in the last column by 20 cents, the freight rate assumed; the fourth column gives the number of pounds of air-dry fiber in 1 ton of wet fiber, found by multiplying 2000 (the number of pounds in 1 ton) by the consistency expressed decimally (thus, $2000 \times .34 = 680$ lb.).

To show how the table may be used, assume for illustration, that the cost of pressing is \$2.50 per ton, consistency of pulp before pressing is 35%, consistency after pressing is 50%, and that the freight rate is 20 cents per ton = 1 cent per hundred pounds. From the third column, it is noted that the cost of freight for 1 ton of air-dry fiber when the consistency is 35% is 57.1 cents, and when the consistency is 50%, the cost is 40 cents; the difference is $57.1 - 40 = 17.1$ cents = saving in freight charges on 1 ton of air-dry fiber when the consistency is increased from 35% to 50%. Since the cost of pressing is \$2.50 per ton, the freight rate (in this case) must be increased to $.20 \times \frac{2.50}{.171}$ = \$2.92 per ton = $\frac{292}{20}$ = 14.6 cents per hundred pounds, since 1 ton = 20 hundredweight. Hence, if the freight rate is greater than 14.6 cents per hundredweight (= 100 lb.) it will pay to press the pulp under the above conditions. Note that the difference between any two numbers in the third column is the saving in cents per ton when the freight rate is 1 cent per hundredweight, because this difference is the saving in cents per ton when the rate is 20 cents per ton = 1 cent per hundredweight. Consequently, for any other freight rate, as r cents per 100 lb., the saving for that rate will be r times the difference.

EXAMPLE.—Under the same conditions as before, but assuming that the freight rate is 25 cents per 100 lb., what would be the net saving?

SOLUTION.—At 1 cent per 100 lb., the saving is 17.1 cents, as found above; hence, for a rate of 25 cents per 100 lb., the saving is $17.1 \times 25 = 428$ cents = \$4.28 per ton. The cost of pressing is \$2.50 per ton; therefore, the net saving is \$4.28 − \$2.50 = \$1.78 per ton of air-dry fiber. *Ans.*

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65. The net saving per ton may be expressed by means of a formula, if desired. Thus, let p = cost of pressing per ton; r = freight rate per 100 lb.; c' = consistency before pressing (expressed decimally); c'' = consistency after pressing; s = net saving. Then, $s = \left(\frac{1}{c'} - \frac{1}{c''}\right) \times 20 \times r - p$, or

$$s = 20r\left(\frac{c'' - c'}{c'\,c''}\right) - p \qquad (1)$$

Substituting in this formula the values given in the example above,

$$s = 20 \times .25\left(\frac{.50 - .35}{.35 \times .50}\right) - 2.50 = \$1.79$$

Should the value obtained by the formula be negative, it indicates that it will then be cheaper to ship without pressing, the saving then being negative. Consequently, the formula will show in any case which method will be the cheaper.

If the rate be given as so much per ton, instead of per 100 lb., the formula becomes, letting r' be the rate per ton,

$$s = r'\left(\frac{c'' - c'}{c'\,c''}\right) - p \qquad (2)$$

To find a formula for the freight rate that will make the extra expense of shipping equal the cost of pressing, make s in formulas (1) and (2) equal 0, since the saving will then be 0, and solve for r, this special value of which may be represented by r_0. Thus, from formula (1),

$$r_0 = \frac{pc'c''}{20\,(c'' - c')} \qquad (3)$$

and from formula (2),

$$r_0' = \frac{pc'\,c''}{c'' - c'} \qquad (4)$$

EXAMPLE.—Assuming the same conditions as in the example of the last article, what must be (*a*) the freight rate in order that the saving in freight will just equal the cost of pressing? (*b*) Suppose the consistency of the fiber to be 32% before pressing and 54% after pressing, the cost of pressing being $2.95 per ton; what must be the freight rate that the saving in freight may equal the cost of pressing?

SOLUTION.—(*a*) Applying formula (3) to find the rate per 100 lb.,

$$r_0 = \frac{2.50 \times .35 \times .50}{20\,(.50 - .35)} = \$.146 - = \frac{250 \times .35 \times .50}{20(.35 - .50)} = 14.6 - \text{cents.}$$

Ans.

(*b*) $r_0 = \frac{295 \times .32 \times .54}{20(.54 - .32)} = 11.6 -$ cents. *Ans.*

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66. Hydraulic Press and Accumulator.—Fig. 24 is an illustration of a hydraulic-press system, including pressure pump and accumulator. The drawing is conventional, because it shows three elevations, (*a*), (*b*), and (*c*), projected on the same plane

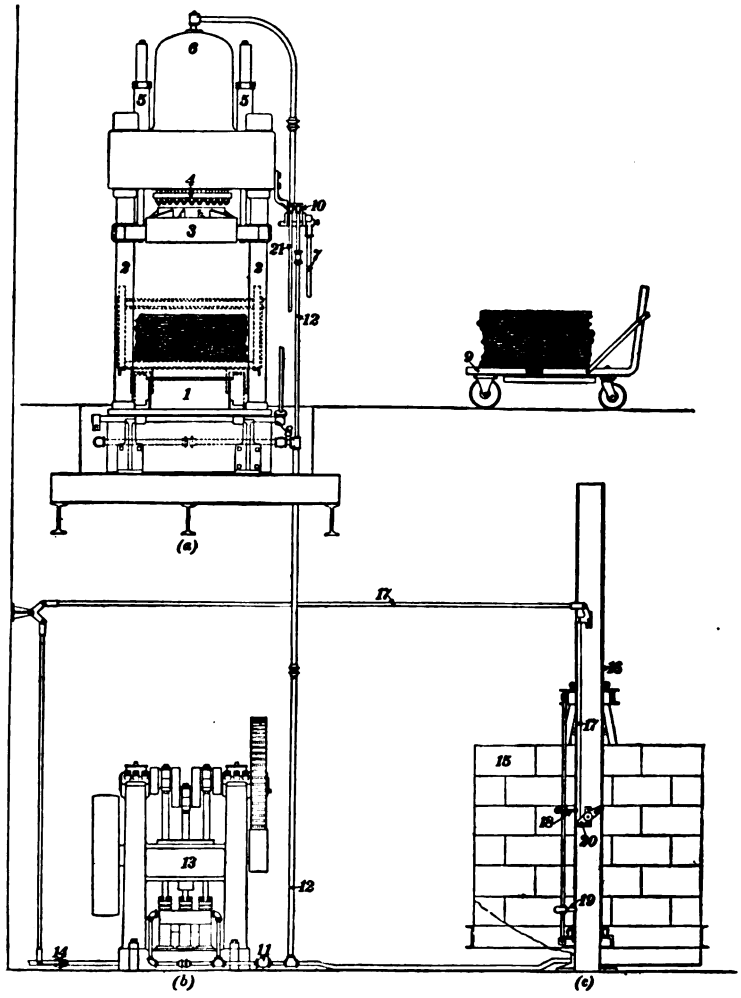

FIG. 24.

but separated. Thus, in reality, (*b*) should be projected on (*a*), since the bases of both machines lie in the same horizontal plane (the floor), as does also the apparatus (*c*). Also, the piping appears much as it would be shown on a plan view, instead of in

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elevation. With this understood, (*a*) is an elevation of the press, (*b*) is an elevation of the pump, and (*c*) is an elevation of the accumulator. The various parts are numbered as follows:

1, support for pulp truck (stationary platen); 2, rods supporting cylinder, forming guides for moving platen, and resisting pressure; 3, moving platen, moves vertically up and down; 4, packing gland; 5, drawback cylinders; 6, pressure cylinder; 7, pressure valve control handle; 8, lever to raise or lower track frame; 9, pulp truck; 10, operating valve; 11, check valve; 12, high-pressure pipe; 13, pressure pump; 14, valve controlling flow of water to pump; 15, accumulator weight; 16, guide for weight; 17, link from accumulator (acts on trip mechanism) to pump control valve; 18, dog (to close valve); 19, dog (to open valve); 20, tripping lever.

The hydraulic presses used for pressing pulp are generally divided into two classes: those in which the piston works upward, and those in which the piston works downward; both have their advantages, but the simpler type is that in which the piston works upward, since the piston then drops automatically (by gravity) when the pressure in the cylinder is released. The other type (piston working downward) requires two special drawback cylinders to draw the piston back (upward) and expel the water from the pressure cylinder before making the next down stroke. The chief advantage of the downward-pressure type is that as soon as the pressure is released, the pulp truck may be removed; in the upward-pressure type, on the contrary, it is necessary to wait for the full descent (return stroke) of the piston before the pressed load can be removed.

67. The press shown in Fig. 24 is of the downward-pressure type. The pressure pump 13 is set in operation and discharges (pumps) water through suitable piping. The water so discharged passes check valve 11, which keeps it from returning to the pump cylinder, and is then delivered to the accumulator (*c*) or to the hydraulic press (*a*), according to whether the valve 10 is open or not. The steel truck 9, having been loaded as previously described in Art. **64,** is run into the press, and is so placed that its center is over the center of the stationary platen, or base, 1; the truck wheels rest on a movable track, which may be raised or lowered by means of suitable levers and cams. This track is then lowered until the body of the truck rests uniformly on the stationary platen 1. Since the wheels of the truck are now unsupported, they carry no pressure when platen 3 is lowered.

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Water at low pressure is admitted to the main cylinder 6, through the low-pressure pipe 21, which causes the piston and platen 3 to move down on the pulp. After platen 3 has moved down about one-third of its stroke, valve 10 is opened and high pressure is turned on until the load is completely pressed. The water in the main cylinder is then released, and the return (draw-back) cylinders 5 pull the piston and platen up, so the press truck may be removed and be replaced with a freshly loaded one.

The time for the entire cycle of operations, that is, the time from when the truck is placed in position until the next truck takes its place, varies, depending as it does upon the degree of dryness desired in the pressed pulp; usually, three presses per hour is the average. For a high dry test (high consistency), 10 minutes under low pressure and 20 minutes under high pressure gives very good results. Time is the important element, when the maximum pressure is to be applied.

During the time when the press operating valve 10 is closed, the discharge from the pump 13 goes to the accumulator (*c*) until the ram, which carries the weight 15, reaches the maximum height of its travel. At that point, the trip mechanism acts to stop the flow of water to the pump, and thus arrests the upward movement of the accumulator ram; because when no more water is admitted to the pump, there will be no more water discharged to the accumulator. The accumulator is nothing more or less than a reservoir for storing potential energy in the form of water under pressure, the pressure being due to the weight 15 (which is very heavy); and since this weight has been raised above its natural (lowest) position, it possesses potential energy. When the weight descends, it forces water out of the accumulator under the specific pressure that is due to the weight 15. One great advantage of the accumulator is that water is supplied by it under high pressure, and that this water is immediately available; also, its action on the load of pulp is that of a dead weight, free from the hammer action so characteristic of direct acting pumps. The weight of the load on the platform plus the weight of the suspended members is the total pressure on the water. The actual pressing effect on the pulp depends upon the relative areas of the accumulator ram and press plunger (or piston) and the area of the pulp touched by the platen.

Several presses may be served by a single high-pressure pump and accumulator. If no accumulator were used, each press

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would require its own separate pump, which would have to be supplied with safety valves, to keep it from bursting when the pressure got too high.

The accumulator is fitted with a tripping device; and when weight 15 reaches the top of its travel, dog 19 engages tripping lever 20, which is set on lever arm 17. Through a system of links and levers (bell-crank levers), the control valve 14 is opened, preventing discharge by the pump of more water into the accumulator. Check valve 11 keeps the water from flowing back from the accumulator, and thus maintains a constant pressure under the accumulator ram. A reverse action is set up when dog 18 engages stop 20; this opens control valve 14 and allows water to flow to the suction end of the pump cylinder.

The pressure in the high-pressure pipe may be as high as 3500 lb. per sq. in., and the total pressure exerted on the pulp may be as high as 600 tons.

68. The actual capacity (output) of a press in tons of air-dry pulp per day depends principally upon: (1) the amount (weight) of pulp per charge that can be handled by the press; (2) the air-dry test (consistency) demanded for the pressed product; (3) the air-dry test (consistency) of the pulp before pressing. In most cases, one pile of laps fills a press; but presses are now built that permit two piles to be inserted side by side and to be pressed simultaneously. The average capacity of single-pile press is, approximately, 12 tons to 20 tons of air-dry pulp per day, depending upon consistency demands and factors given. The capacity of double-pile presses may run as high as 33 tons per day.

The water supply for the high and low pressure pumps should be very thoroughly filtered and used over and over again, since the presence of grit in the water causes scoring of the pistons and plungers and wears out the packing.

Metallic, woven hemp, and cup leather packing are all used. The length of life of these packings depends upon the cleanliness of the water and the nature of the surface of the pistons and plungers that rubs against them. A close-grain bronze covering for the piston increases the life of the packing from three to four times, while a chilled-iron piston surface that has been ground to a high polish gives practically the same results, as far as packing life is concerned. Ordinary cast-iron pistons wear out the packing very fast.

It is advisable to have each press equipped with a recording

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pressure gauge, so that every cycle of its operations is reported and a true record of the day's operations is available. When operating these presses, it is important that all valve seats be kept properly ground and that the relief valves be properly set. The press itself should be inspected to see that the four posts supporting the press are all tight and that each bears its proper share of the load.

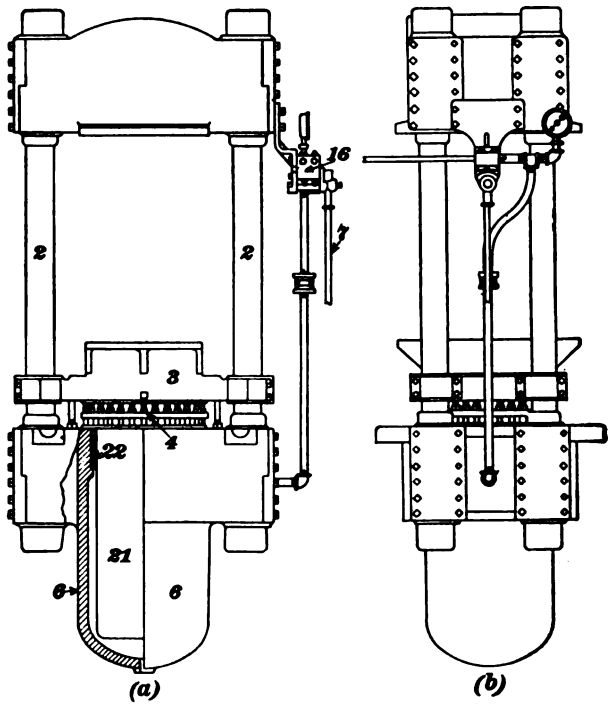

FIG. 25.

67. Upward-Pressure Type of Hydraulic Press.—Fig. 25 shows a press of the upward pressure type. The parts are numbered in the same manner as in Fig. 24, except that rods 2 support the stationary head, 21 is the plunger or ram, and 22 is packing. The press only is shown, (*a*) being a front elevation (partly in section), and (*b*) is a side elevation. The cylinder is below the floor level, and no track raising device or drawback cylinders are required.

In operation, the loaded pulp truck is run into the press. The operating valve is opened to admit water at low pressure, to

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reduce (press out) the greater amount of water in the pulp at a fairly rapid rate, 10 minutes being usually allowed for this. The pressure is then shifted to high, and is allowed to stand thus for from 15 to 20 minutes. After the pressing is completed, the valve is opened to relieve the pressure and the ram, with the pressed pulp, descends to the floor level.

The low pressure usually ranges from 1000 to 1500 lb. per sq. in. For a 24-inch ram (plunger) and a total pressure on the pulp of 600 tons, the high pressure is 2650 lb. per sq. in., obtained as follows: Area of cross section of plunger = $.7854 \times 24^2 = 452.4$ sq. in.; load on plunger is 600 tons = 1,200,000 lb.; load per square inch = $1{,}200{,}000 \div 452.4 = 2652$ lb.; hence, pressure on plunger must be about 2650 lb. per sq. in.

DRYING MACHINES

70. Purpose of Drying Machine.—When a mill wishes to produce pulp having a higher consistency than 60% air-dry fiber, which is about the extreme limit that can be had by pressing, a drying machine is required. The process consists in forming a sheet of pulp, pressing out as much water as can conveniently be done, evaporating as much more water as is necessary to get the desired degree of dryness, and winding the sheet into rolls or cutting it into smaller sheets.

Two types of machines for drying pulp are in use, the *cylinder type* and the *Fourdrinier*, the former being the more common. The only essential difference between the two types lies in the sheet-forming part. These machines are practically identical with the paper and board machines, described in detail in the Section entitled *Paper Making Machines*, but will here be referred to briefly with regard to their use for drying pulp.

71. Cylinder Type of Drying Machine.—Fig. 26 shows a single-cylinder drying machine[1]; only one vat is here used, but more may be used. The vat *A* is filled with pulp to a constant level and contains a revolving cylinder *B*, covered with wire cloth, through which water in the stock flows; as the water flows

[1] On account of the extreme length of the machine as compared with its height, the machine is shown cut in two on the drawing, the left-end part being placed over the right-end part. If the latter were cut out and placed alongside the upper part, the complete machine would then be represented as a single drawing.

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through, a layer of pulp is left on the wire. The layer of pulp is picked off the wire by the felt C, which is pressed against the

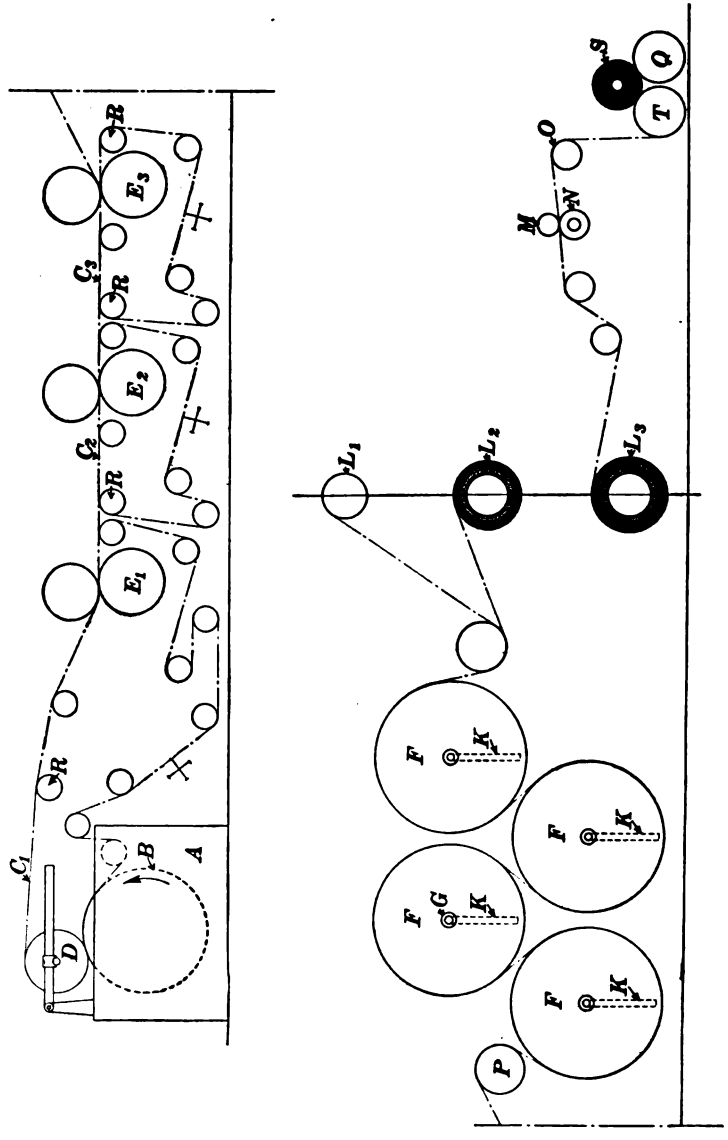

FIG. 26.

cylinder (mold) B by the couch roll D. The felts C_1, C_2, etc. carry the sheet of pulp through several wet presses E_1, E_2,

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etc., each having an upper and lower roll, which squeeze out considerable water. The felts are supported by the rolls R, placed at convenient distances apart. Only three presses are shown in the illustration, but some machines have more. The crosses represent felt washers.

72. Dryers.—The beginning of the process is the same as for the first part of the machine shown in Fig. 20. The sheet then passes to the dryers F, to which point, from press rolls E_3, it is strong enough to be carried without support. As the sheet enters

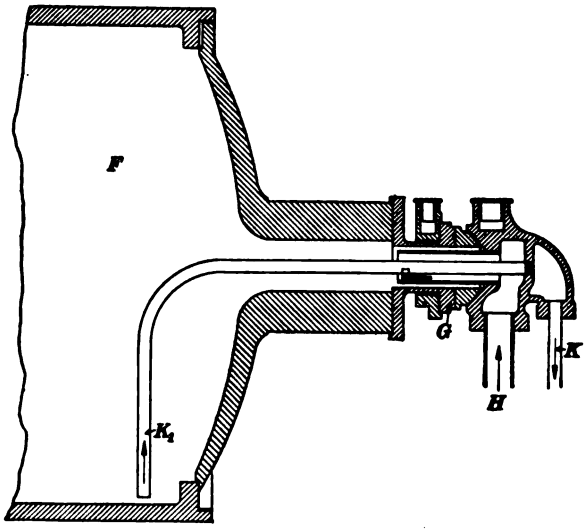

FIG. 27.

the dryers, it contains approximately 60% water. The dryers F are cast-iron cylinders, 48 in. to 54 in. in diameter and somewhat wider than the width of the sheet. Steam at low pressure is introduced into each dryer through a special joint G in the rear bearing (shown in detail in Fig. 27), and from which is removed the water formed by the condensation of the steam.

Thus, referring to Fig. 27, F is the dryer and G is the special joint. Steam enters through a pipe H and fills the dryer, the greater part of the air in the dryer escaping through a pet cock in the head of the dryer. The steam gives up a part of its heat to the shell of the dryer, which in turn heats the pulp and dries it. As the steam loses heat, it condenses, and the water thus formed is removed by means of the siphon K_1 which operates by reason

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of a slight excess of pressure in the dryer over that in the header to which pipe K is connected, or because of a current of steam through it. The water may also be removed by scoops or dippers fastened to the shell, which deliver to an outlet through the steam joint as they are raised by the rotation of the dryer. This latter action may be explained by imagining water to be scooped up in a dustpan and raised until the water runs out through the handle and down one's sleeve. After leaving the joint, the water may be run into a pipe fitted with steam traps or into a receiver ("hot well"). In the latter case, when the machine is shut down, the water should be drawn off to a point below the opening to the pipe from the dryer or else the air vents in the dryer heads should be opened; otherwise, the vacuum formed by the condensation of the steam left in the dryers may draw water back into them. It is to be noted that dryers may be arranged on vertical supports, as many as nine (9) in a set.

73. Reels.—On leaving the dryers, Fig. 26, the sheet of pulp may contain from 80% to 95% bone-dry fiber, depending on the speed of the machine, thickness of the stock, temperature of the dryers, etc. This sheet is then wound on reels L_1, L_2, L_3 (see lower part of figure). Each reel drum is connected by gears to a pulley that is driven by a slack belt, means being provided for regulating the tightness of the belt, so as to permit the belt to slip as the roll grows in diameter. If the belt did not slip, either it or the sheet must break, since the increasing size of the roll increases the peripheral velocity, which increases the pull on the sheet, the speed of the sheet on the machine remaining constant. This is also true of re-winding shafts that are driven at the center. A clutch permits an empty drum to be connected with the power and allows the full-wound drum to be disconnected, or "thrown out."

74. Slitter and Winder.—The reels just described are the full width of the machine. For purposes of shipment, the sheet is cut into strips by slitters M, Fig. 26 (lower part), and these strips are wound into rolls of convenient size. The slitter is a saucer-shaped steel disk M, held by a spring against the edge of a collar N on a shaft driven by a belt. Both collar and slitter are set and fastened by headless set screws, and are spaced according to the width of sheet desired. The sheet is fed in from the back, the strips passing over the roll O, up between T and Q, and wrapped around cores placed on shaft S, unless some type of

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collapsible shaft is used. (A *collapsible* shaft has a removable segment; when removed, this relieves the grip of the pulp sheet, and the shaft can then be pulled out.) Roll T is driven by a slack belt; the speed is controlled by the tightness of the belt, which is altered by adjusting the belt tightener. The friction between the roll and the pulp sheet gives the motion that winds the strips on S, the roll so formed riding on rolls T and Q. As the roll of pulp grows, it gets heavier and tends to wind tighter. The pressure due to this weight may be relieved by some kind of a counterpoise, which is, however, not always employed on pulp-drying machines. It is to be noted that the speed of pulp sheet is the same as the peripheral speed of roll T (which it touches), which is practically constant. In the older type of winder, the shaft S was direct driven, and, as a consequence, the peripheral speed of the roll S increased in proportion to the increase in diameter of the roll. As many shafts are used as there are rolls to be wound (usually 2 or 3), and all are connected by gears. The winder just described is called a **differential winder,** because of the gear that permits rolls of different sizes to be wound simultaneously and with the same peripheral speed.

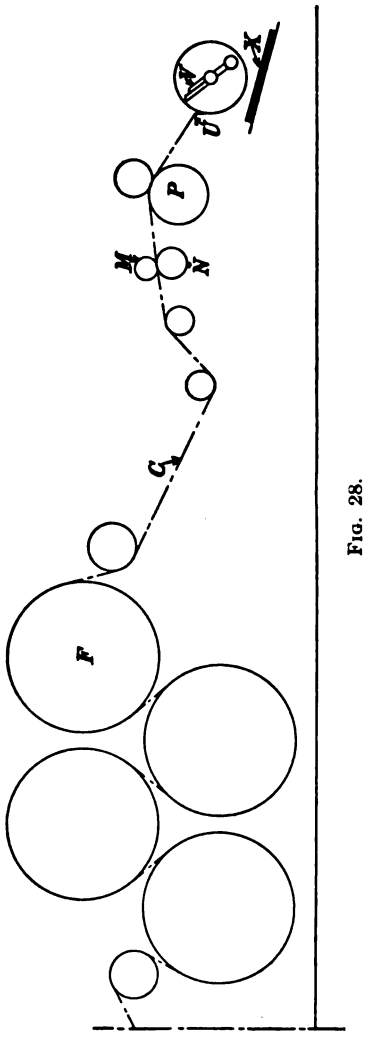

FIG. 28.

75. Slitter and Cutter.—When dry pulp is to be shipped in bales, it must first be cut into sheets. This is accomplished by cutting the continuous web of pulp into strips of the desired width

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and then cutting the strips into sheets of the desired length. Referring to Fig. 28, the part here shown may be regarded as replacing the lower part of Fig. 26. The web of pulp *C* usually comes direct from the dryers *F* and is cut by the slitters *M*. The strips then pass over the drum *P* and the stationary knife *U*, which is sometimes allowed a slight motion against heavy springs, to take up the shock of the revolving knife *V*. This knife is set at a slight angle to the axis about which it revolves, in order to get a shearing action when cutting. To understand this last statement, note that the web is fed over the stationary knife blade *U*, the end passing down and over the top of the tray *X*, the edge of *U* being at right angles to the direction of motion of the web. If the edge of the revolving knife were so adjusted that when one end of it touched *U*, the edges of both blades would touch all the way across, the action of *V* would be like a punch entering a die, it would *push* the sheet cut off in front of it and past the edge of *U*. But if the cutting edge of *V* be so adjusted that one end is slightly higher than the other, then the various points along the edge of *V* go past the edge of *U* one after another instead of simultaneously, which creates a better shearing action, the effect being much the same as in the case of a pair of shears.

The length of the sheet cut off depends upon the relative speeds of the web and the knife *V*. Assuming the speed of the web to be uniform (as is the case), the faster *V* revolves the shorter will be the sheet cut off, and the slower the speed of *V* in revolutions per minute the longer the sheet cut off. The speed of *V* is varied by shifting the belt that drives it along the cone of a cone drive. As the cut sheets drop into the tray *X*, they are removed by hand and are piled on trucks for baling. When import regulations of countries to which the pulp is exported demand it, the pulp may be perforated, *i.e.*, "damaged" to prevent its use for printing purposes, by passing it over a roll having spikes on its surface. Bales are made by piling the sheets on sheets of pulp as wrappers, pressed in a press as described in Art. **82**, and bound with wire or iron bands.

76. Wet Part of Fourdrinier Pulp-Drying Machine.—The wet end of a pulp-drying machine (known as the **Fourdrinier type**) that is used in Europe, but which is found in few mills on this continent, is shown in Fig. 29; the other end, from the dryers out, may be the same as in the machines described in Figs. 26 and 28.

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The stock, which has a consistency of between 1% and 2%, is admitted at a constant rate of flow to the flow box *A* at the inlet *O*. The flow is controlled by a regulating box, one type of which was explained in Art. **53**. The Fourdrinier part consists essentially of an endless wire cloth *B*, supported by the breast roll *C*, table rolls *D*, guide roll *E*, lower couch roll F_1, wire rolls *G*, and stretch roll *H*. The couch roll is driven, and by its turning drives the wire. If the wire begins to work toward the back of the machine, a gear is set in motion, which carries the front end of the guide roll backward (toward the breast roll); if the wire comes too far forward, the front end of the guide roll is pushed toward the couch roll; in either case, the fault is corrected. This mechanism, and other details of the machine, are fully described in the Section entitled *Paper Making Machines*.

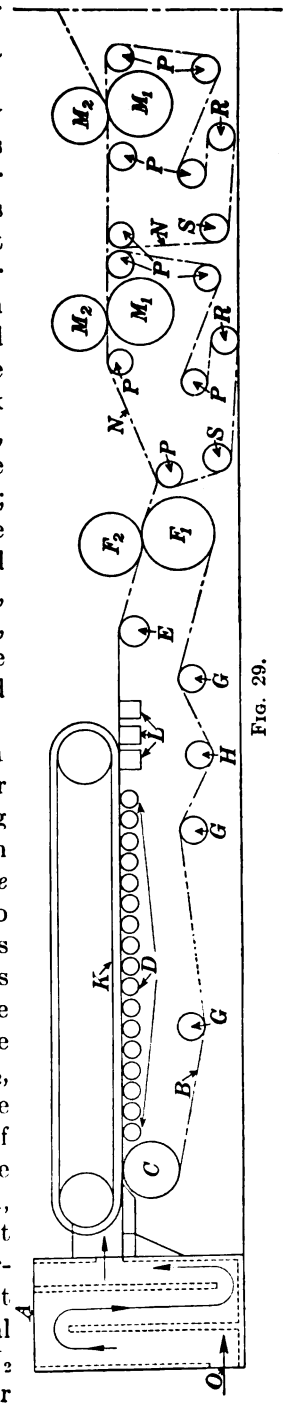

FIG. 29.

The stock flows from the flow box *A* to the wire over a flat apron of rubber or oil cloth; it is kept from spilling over the sides by a rubber strap *K* on each side of the wire, called *deckle straps*. Water immediately begins to drain through the wire, and the fibers settle and felt together. More water is extracted by the suction boxes *L*; some is squeezed out, and the sheet is more firmly pressed, by the couch roll F_2, which rides on the wire just behind the center of the lower couch roll F_1. If greater pressure is desired than can be secured by the weight of the couch roll, weights may be added to a lever that pulls down on the upper couch-roll bearing. From the couch roll, the sheet (web) of pulp passes through several presses, each having an upper roll M_2 and a lower roll M_1, where more water

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is squeezed out. The pulp is supported and carried by felts *N*, which run over felt rolls *P*, stretch rolls *R*, and guide rolls *S*, which are generally adjusted by hand. The dryers, winders, etc. are the same as for a cylinder machine.

77. The Dryers.—The function of the dryers is to evaporate water from the pulp, and the condition of the atmosphere is an important factor in this operation, since dry air will absorb more water vapor than moist air and warm air will absorb more than cold air. Since it is not practicable to dry the air that surrounds the dryers, the best results are obtained by warming fresh air until a temperature is reached at which the volume supplied the dryers per hour will absorb the amount of water evaporated.

The thicker the stock supplied to the machine the less water there is to remove, but there is a limit to the degree of concentration that will produce the best and most economical results.

78. Air Dry.—The term **air dry** is one that is constantly used in a pulp mill; the term **dry pulp** usually means that the pulp is air dry, that is, that it contains 90% of actual fiber and 10% of moisture (water). If, say, 600 grams of dry pulp be put in an oven and completely dried, there will remain $600 \times .9 = 540$ grams of bone-dry fiber, 60 grams of water having evaporated. If, however, only 432 grams, say, should remain, the per cent of bone-dry fiber in the original sample would be $\frac{432}{600} \times 100 = 72\%$, and the per cent of air-dry fiber would be $72\% \div .9 = 80\%$. Therefore, if a car load of such pulp weigh 43,860 lb., it will contain $43{,}860 \times .80 = 35{,}088$ lb. of air-dry pulp, or $43{,}860 \times .72 = 35{,}088 \times .90 = 31{,}579.2$ lb. of bone-dry pulp.

It is obvious that pulp may be more than 100% air dry, that is, it may contain less than 10% of water; for instance, if it contain only 8% of water, it will be $\frac{100 - 8}{90} \times 100 = 102\frac{2}{9}\%$ air dry.

HANDLING OF PULP FOR SHIPMENT

79. Wet Pulp not Pressed.—Wet pulp as it comes from the wet machines is usually loaded on a truck and is then taken to a car, which previously has been swept out and lined with dry pulp on the walls; layers of dry pulp are also placed on the floor of the car. The pulp should be piled in the car in tiers, one lap

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above the other, with an occasional overlapping, so as to form a binder; in cold weather, care should be taken to place these laps as nearly as possible in neat piles to facilitate unloading. A good plan, in order to prevent freezing of pulp to the floor of the car, is to lay strips of wood, 2″ × 2″, crosswise on the car floor and pile the laps on these. A better method is to use a wooden platform or skid and pile the pulp on this platform in the shipping room, until there is a load of about 1800 lb. on the platform. Then an elevating truck is run under this platform and taken into the car, the truck is removed, and the load left in the car. This method obviates the handling of pulp more than once; also, at the receiving end, the pulp is very easily unloaded from the car. Loads on such skids or platforms could be made up to certain standard weights, say 1800 lb. or 2000 lb.; an air-dry test could be made of each load, and this wet weight and test marked on a card and attached to such load. This would give the receiving mill definite knowledge as to how many pounds of pulp was in each load, which would be of great assistance in storing and in charging beaters.

80. Wet-pressed Pulp.—The purpose and operation of the hydraulic press have been described in Art. **66.** The output per press to obtain 60% air-dry pulp is about 1.2 tons per hour. The same instructions as previously given in handling all wet unpressed pulp should be observed in loading and shipping of the pressed pulp.

The Report of the Special Committee on the Standard Unit Weights of Pulp of the Connecticut Valley Branch of the Cost Association of the Paper Industry deals with the variation of the weights of wet pulp. The following suggestions are made.

1. Steady flow of stock to the wet machines should be maintained.

2. The stock should be of uniform consistency.

3. The presses on wet machines must have a uniform pressure or otherwise the air-dry test obtained from laps will vary greatly.

4. The operator taking the laps off the wet machines should have a bell or some attachment on the machine so that when a lap is of a desired thickness this attachment or bell would notify the operator and he would then cut the lap off.

81. Dry Pulp in Rolls.—Soda pulp is always shipped in rolls, groundwood pulp is always in laps, either wet or pressed; sulphite

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and sulphate pulp may be in laps, sheets, or rolls. Roll shipments require that the cars should be thoroughly cleaned and lined with some strong wrappers, such as kraft paper, or a lining of sulphite itself might be used. The rolls should be wound as tightly as possible, and the rolls should be of uniform weight and moisture content. Each roll should be tied with stout twine, in order to insure that in the handling it will not come unwound. In loading cars, it is usual to load such rolls on trucks that will accommodate 10 rolls, so as to facilitate the checking of the number of rolls in a car. In the car, the rolls are placed on end and are packed as closely as possible. A sheet or two of pulp may then be laid over the first layer, and a second layer packed in as before. The car should be packed full, to avoid jolting and breaking of rolls. For ocean shipment the rolls are tied with wire.

82. Baling of Dry Pulp.—The dry sheet as it comes from the machine is run through a cutter, and sheets are made usually 24″ × 36″ or any other size desired. These sheets fall from the cutter into a stand, where the winder boys pick them up and place them on the truck, which is on a scale. The scale is usually situated close to the cutter, and a truck that will run into the baling press is placed on the scale. On the bottom of this truck, there is usually an iron plate fastened, and so cut as to facilitate the passing of the bale ties under the sheets, see Fig. 30. A similar plate is also placed on the top platen of the hydraulic press. Two wrappers, generally of the same quality as the dry pulp in the bale, are placed on the bottom of this truck. These are large enough to form half the cover of the bale. The tare of the truck is allowed on the scale and a 400- or 500-pound weight is added for whatever the desired weight the bale is to be. An iron frame is usually placed on the truck, to guide in the building of the bale. When the bale is of the required weight, the truck on which bale is made is taken from the scale and placed under the hydraulic press. Two wrappers which have been weighed in along with the bale, for the top cover of same bale, are then placed in position, and the hydraulic press is then placed in operation. Baling wires, usually 10 gauge, are run

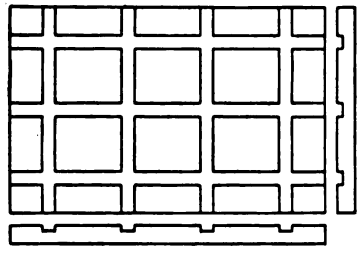

FIG. 30.

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around the bale, two or three on the 24″ side and three or four on the 36″ side of the bale. When the pressure has reached its highest point, the wires are fastened together and the pressure is then released. The usual size of a bale of 500 lb. is 20″ × 26″ × 36″. A bale of 400 lb. is 16″ × 26″ × 36″. In handling such pulp, two men will handle 4 tons of air-dry pulp per hour in 400 lb. bundles; however, they attend only to the wiring of the bales and the operation of the press. It requires 5 h.p. per ton of air-dry pulp to bale the pulp. One hydraulic press will handle 2 tons per hour of 400 lb. bales and 2½ tons per hour of 500 lb. bales. Another type of press often employed for baling pulp and paper is operated by a toggle joint, instead of hydraulic pressure.

QUESTIONS

(1) Explain the process and purpose of "lapping?"

(2) (*a*) What kind of pulp is handled on a multi-press wet machine? (*b*) What are the essential features of this type?

(3) What principle is applied in each of two different types of save-alls?

(4) Explain the operation and purpose of the accumulator for a hydraulic press.

(5) What is the principal difference between the cylinder and Fourdrinier types of pulp-drying machines?

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WEIGHTS, VOLUMES, ETC., OF LIQUID PULP STOCK CARRYING VARIOUS PERCENTAGES OF AIR-DRY STOCK

GALLONS (U.S.)

% or lb. dry stock in 100 lb. liquid	Lb. dry stock in 1 cu. ft. liquid	Number of cu. ft. containing 1 lb. stock	Lb. dry stock in 1000 gal. liquid	Number of gal. containing 1 lb. stock	Cu. ft. liquid per minute per ton dry stock per 24 hr.	Gal. liquid per minute per ton dry stock per 24 hr.	Lb. liquid per minute per ton dry stock per 24 hr.	Lb. water per lb. stock	Gal. water per lb. stock	Gal. water per ton stock
0.10	0.0625	16.00	8	119.55	22.22	166.20	1388.88	999.00	119.36	238710
0.20	0.1250	8.00	17	59.77	11.11	83.10	694.44	499.00	59.50	119996
0.25	0.1562	6.40	21	47.87	8.88	66.49	555.55	399.00	47.75	95511
0.30	0.1875	5.33	25	39.90	7.41	55.41	462.96	332.33	39.78	79553
0.33	0.2063	4.80	28	35.91	6.66	49.86	416.64	297.10	35.55	71094
0.35	0.2187	4.57	29	34.20	6.35	47.50	396.83	284.71	34.08	68154
0.40	0.2500	4.00	33	29.92	5.55	41.56	347.22	249.00	29.80	59605
0.45	0.2812	3.66	38	27.43	4.94	36.94	308.64	221.22	26.48	52955
0.50	0.3125	3.20	42	23.92	4.44	33.25	277.77	199.00	23.82	47636
0.55	0.3437	2.91	46	21.76	4.04	30.22	252.52	180.82	21.64	43284
0.60	0.3750	2.66	50	19.94	3.70	27.71	231.48	165.66	19.83	39656
0.65	0.4062	2.46	54	18.41	3.42	25.57	213.68	152.85	18.29	36569
0.70	0.4375	2.28	58	17.10	3.17	23.75	198.42	141.86	16.98	33957
0.75	0.4687	2.13	63	15.96	2.96	22.16	185.18	132.33	15.84	31678
0.80	0.5000	2.00	67	14.96	2.78	20.78	173.61	124.00	14.84	29683
0.85	0.5312	1.88	71	14.06	2.61	19.56	163.40	116.65	13.96	27922
0.90	0.5624	1.83	75	13.71	2.47	18.47	154.32	110.11	13.18	26358
0.95	0.5937	1.68	79	12.61	2.34	17.50	146.19	104.26	12.48	24958
1.00	0.6250	1.60	84	11.97	2.22	16.62	138.88	99.00	11.85	23698
1.25	0.7812	1.28	104	9.57	1.78	13.30	111.11	79.00	9.45	18911
1.50	0.9375	1.07	125	7.98	1.48	11.08	92.59	65.66	7.86	15719
1.75	1.0937	0.91	146	6.84	1.27	9.50	79.37	56.14	6.72	13439
2.00	1.2500	0.80	167	5.97	1.11	8.31	69.44	49.00	5.86	11729
2.25	1.4062	0.73	188	5.49	0.99	7.39	61.73	43.44	5.20	10399
2.50	1.5625	0.64	209	4.79	0.89	6.65	55.55	39.00	4.67	9335
2.75	1.7187	0.58	230	4.35	0.81	6.04	50.50	35.36	4.23	8465
3.00	1.8750	0.53	251	3.99	0.74	5.54	46.29	32.33	3.87	7740
3.50	2.1875	0.46	292	3.42	0.63	4.75	39.68	27.57	3.30	6600
4.00	2.5000	0.40	334	2.99	0.55	4.15	34.72	24.00	2.87	5745
4.50	2.8125	0.36	376	2.74	0.49	3.69	30.86	21.22	2.54	5080
5.00	3.1250	0.32	418	2.39	0.44	3.32	27.77	19.00	2.27	4536
5.50	3.4375	0.29	459	2.18	0.40	3.02	25.25	17.18	2.06	4113
6.00	3.7500	0.27	501	1.99	0.37	2.77	23.15	15.66	1.87	3750

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TREATMENT OF PULP

EXAMINATION QUESTIONS

(1) If the consistency of the stock in a pulp storage tank is 4.7%, what is the weight of air-dry fiber if the diameter of the tank is 20 ft. and the depth of stock is 10 ft.? Take the weight of a cubic foot of stock as 62.4 lb. *Ans.* 9214 lb.

(2) What depth would be filled if the consistency had been only 3.5%, the weight of air-dry fiber being the same as in question (1)? *Ans.* 13.4 ft.

(3) Distinguish between coarse screening and fine screening of pulp.

(4) How much (*a*) good fiber is lost in screening out groundwood slivers? (*b*) how can this loss be reduced? (*c*) on the basis of your figures how much money is lost in this way each year by a mill making 80 tons of groundwood per day, if the pulp is worth, say, $50 a ton?

(5) Explain the principle and purpose of riffling.

(6) What is the purpose of fine screening and what factors affect this operation?

(7) How is No. 2 stock obtained in the screening process and how can it be disposed of?

(8) What is meant (*a*) by the term "diaphragm" screen? (*b*) how does it work?

(9) Explain the principle of the centrifugal screen.

(10) Sketch the principal parts of a pulp thickener and tell how it works.

(11) (*a*) What is the advantage of regulating the consistency of pulp? (*b*) What is the relation between the consistency of pulp and the friction in a pipe?

(12) Assuming a freight rate of 15 cents per 100 lb. what would be the saving, if any, per ton, by pressing pulp from a consistency of 35% to a consistency of 55%, if the cost of pressing is $3.00 per

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ton of air-dry pulp? Calculate (*a*) by using table Art. **64,** (*b*) by using formula Art. **65?**

Ans. { (*a*) 10.5 cents gain.
(*b*) 11.7 cents gain by pressing.

NOTE.—The difference in these two results is caused by the fact that the values given in the third column of the table are not carried to more than one decimal place.

(13) Why is lap pulp often pressed?

(14) Explain (*a*) the principle of the hydraulic press; (*b*) what factors influence its capacity?

(15) State briefly the meaning and function of the following parts of a cylinder-type pulp-drying machine: cylinder; couch roll; wet press rolls; dryers; siphon; reels; slitter; winders; cutter.

(16) A car of pressed groundwood pulp weighs 44,650 lb.; a sample weighing 2400 g. was taken and dried, and gave a bone-dry weight of 1170 g. Find (*a*) the percentage of air-dry pulp in the sample and (*b*) the weight of air-dry pulp in the car.

Ans. { (*a*) 54%.
(*b*) 24,111 lb.

(17) What points should be observed in loading pulp in freight cars?

(18) What are (*a*) the usual sizes and weights of bales? (*b*) how are they made?

(19) If a sample of pulp is 87% bone-dry, how much air-dry fiber is contained in a bale weighing 500 lb.? *Ans.* 483.3 lb.

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SECTION 8

REFINING AND TESTING OF PULP

(PART 1)

By T. E. KLOSS, B. S.

REFINING OF PULP

INTRODUCTION

1. Definition.—As a process in the manufacture of pulp, **refining** means so treating the screenings that material which would otherwise be wasted may be successfully used in making certain grades of paper and boards. The screenings include large fibers, slivers, knots, etc., that have been separated from good fibers in previous screening processes. The Section on *Treatment of Pulp* described the methods and apparatus used in screening the pulp as it comes from the grinders or digesters and the treatment of the accepted stock; this Section deals with the treatment of the stock rejected by the screens.

2. Knots, Slivers, Shives, etc.—The material that is comprised under the terms *knots*, *slivers*, and *shives* is the waste product from the chemical pulp and groundwood processes; it invariably carries some good fiber that adheres to it in the screening process. The difference between shives and slivers should be clearly understood. A **shive** may occur in mechanical (groundwood) or chemical pulp, and consists of a very small bundle of fibers that have not been separated completely. This bundle is a little thicker than the majority of the fibers; it shows up in the paper as a small, dark or shiney blotch. The **sliver** is, in reality, a small splinter; it is longer than a shive, and is of smaller diameter in proportion to its length. Slivers are found more frequently in mechanical than in chemical pulp.

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3. Cause of Slivers, Shives, etc.—Knots and uncooked chips are always associated with the chemical pulp processes, and they often occur in large quantities, depending on the nature or treatment of the wood. This material is left as a waste product, because it contains more resinous material than the good wood, and, because of this, requires a much longer time to reduce to fibers than the perfect wood. If cooking conditions were adjusted to reduce the knots, much fiber would then be destroyed. Furthermore, the knots are usually slightly colored; consequently, their removal improves the color of the pulp. It is obvious, then, that when the chemical process has gone as far as is practicable, a mechanical process of refining must be used to reduce the knots and uncooked chips to a useful state. It may here be remarked that this material really contains the longest and toughest fibers. Oftentimes, the product is coarser after refining than the good fiber obtained by cooking; but by again classifying, or separating, the different grades, a certain percentage of the refined pulp may be used with the good pulp. The remaining coarser grades may be once more refined or taken out at this point and made into laps, with the aid of the wet machine, and sold as screenings, for the manufacture of board or wrapping paper.

Similarly, in the groundwood process, there are slivers, shives, and white shiners, which vary in size and character, according to the condition of the surface of the grindstone during grinding. That is to say, over the surface of the stone, directly after sharpening, there are high ridges that tear the fibers from the wood instead of grinding them off; likewise, the degree of pressure applied, and other conditions, has the effect of producing shives, slivers, or white shiners. The presence of these is sometimes due to battering, or "brooming," of the ends of logs or blocks, caused by driving water or tumbling in barking drums. This waste product, as in the case of chemical pulp, comes under the head of groundwood screenings, and is refined in much the same way as chemical pulp screenings. There is, however, a notable difference in appearance between the chemical pulp and the groundwood screenings, which is due principally to the fact that one is cooked and the other is raw.

4. White Shiners.—The **white shiner** is a glossy, white fiber, and occurs in the groundwood pulp or in an undercooked sulphite stock. Its character and appearance is unchanged, even after it appears in the finished paper, unless it has been reduced by re-

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fining. By holding the sheet up to the light, these shiners may readily be picked out. In colored papers, shiners will not take the dye, and they cause an unsatisfactory sheet of paper.

5. Diagram of Refining Process.—The diagram, Fig. 1, shows the position of the refiners with respect to the screens; it also shows how the stock is circulated in a refining system. The stock to be refined first enters rotary screens at *A*, which have .065-inch slots or perforations. The *accepted stock*, the stock that passes these screens, much of which is good fiber that adhered to the knots or slivers, goes to the paper mill or to the wet machines.

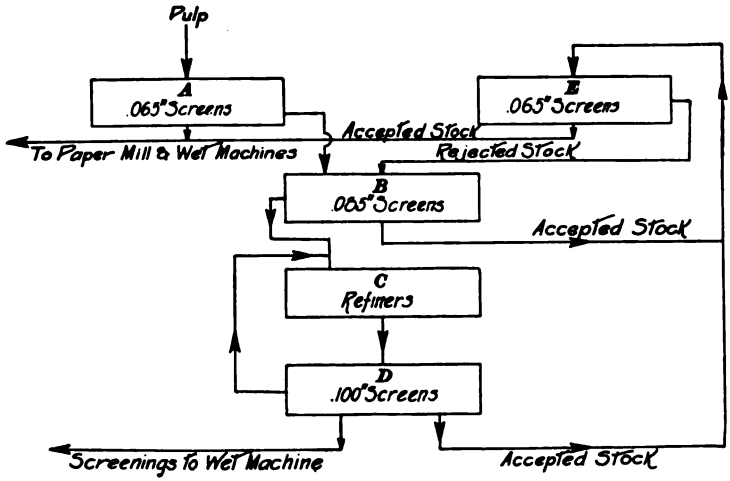

FIG. 1.

The rejected stock, the stock that is retained on the .065-inch screens, is again screened in rotary screens *B*, which have .085-inch slots. The accepted stock from the .085-inch screens is returned to one of the .065-inch screens *E*, or it may be mixed with stock entering from the main screening system; but separate screens for screenings will keep the paper supply cleaner. At this point, *E*, the rejections from the .085-inch screens pass to the refiners *C*, which will be described in detail later. The refiner crushes and rolls out the hard bundles mechanically, leaving a partially refined pulp, to be again classified by screening through rotary screens *D*, which have .100-inch slots. The accepted stock from this last screen also returns to the .065-inch screens *E*, or to the main screens, and follows the same cycle as the original stock furnished to the refining system. The rejected

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stock from these last screens *D* returns to the refiners, unless there is too large a mass stock for these screens to handle. In this latter case, an overflow is provided for leading the excess to one or more wet machines, which turn the screenings out in laps, to be sent away to the market. Under ordinary conditions, the stock is circulated again and again, until a refined pulp is produced from the bulk of the screenings. Some mills omit screen *D*.

The use of a refiner system enables a mill to operate more successfully and economically than when the knots, slivers, etc., are wasted.

6. Separating Waste Products from Perfect Fibers.—In addition to the saving of a great bulk of waste product by refining, there is also the necessity of separating the waste product from the perfect fibers, in order that none of the coarse material shall reach the paper machines, and to prevent the waste of good fibers adhering to the screenings. It will be seen later, in connection with paper making, how easily the paper on a paper machine will "break down," if a sliver or coarse fiber is allowed to get on the machine. Moreover, the occurrence of coarse fibers lowers the grade of paper; and if a sheet of such paper pass the machine successfully and is not culled out, it may cause complaints. The occurrence of dirt, coarse fibers, bark, etc. should be considered as a flaw, just as a speck or bubble in glass or steel is so considered.

REFINERS

7. Types of Refiners.—There are various types of refiners, all intended to produce the same ultimate result. It is not the purpose here to state which is the best refiner, but to describe the leading types of refiners, and to point out the duties they perform. The various types are comprised under the following heads, a number of machines of each type being on the market: (*a*) return of slivers to grinders; (*b*) ball mills; (*c*) disk refiners; (*d*) kollergangs; (*e*) stone roll beaters; (*f*) Jordan engine; (*g*) miscellaneous. Each of these types will now be considered, and in the above order.

8. Return of Slivers to Grinders.—The return of slivers to grinders is probably one of the oldest methods of refining screenings, and need only be mentioned here, since the grinders have been discussed in another Section. The screenings are intro-

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duced, with water, in front of a pocket, so that the fibers will be rubbed between the stone and the wood, in the pocket.

9. Ball Mill Refiner.—This type of refiner, shown in Fig. 2, consists of a cylindrical shell *A*, with cast-iron heads *B*, and is mounted on bearings *C*, at both ends of the shell, by hollow trunnions *D* and D_1. The shell is made to revolve, without vibration, at about 26 r.p.m. by the girth gear *L* and the pinion, etc. *P*. The shell is lined with hardwood blocks *E*, and is filled to about half full with pebbles *F*. The pebbles are of the best

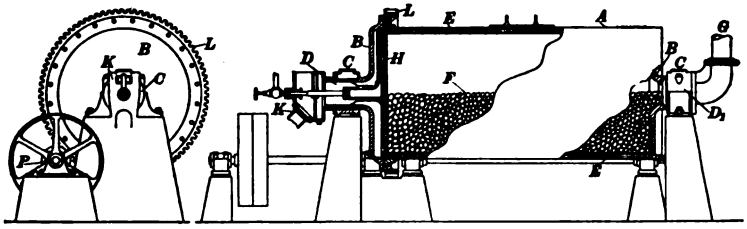

FIG. 2.

quality, hand-picked, French flint, and their average size is 2 inches diameter by $3\frac{1}{4}$ inches long. The material to be treated is fed continuously from an adjustable feed box by pipe *G*, through the hollow trunnion D_1. As the shell revolves, the stock is exposed to the rubbing and rolling action of the pebbles, which reduce it to pulp. The pulp is discharged continuously through the hollow trunnion *D*, at the opposite end from the feed. A slotted screen plate *H*, inside the drum and near the discharge trunnion *D*, allows the passage of the pulp, but keeps the pebbles inside the machine. Provision is made for supplying the proper amount of water in the refiner, so the stock may be thick during the treatment and diluted for discharge. The pulp is discharged over a special weir box *K*, which automatically maintains suitable conditions within the machine. The consistency of the stock is about 4% to 5%, air dry; if too thin, a decker or other thickener may be used to concentrate the feed.

10. In mills where the production of screenings runs below 5000 pounds, dry weight, in 24 hours, it is found most economical to store the screenings in a wooden tank that is fitted with an agitator. If this tank has a perforated bottom, the screenings may be drained here and the decker may be dispensed with. When the tank is full, the refiner is started; and the screenings

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are fed to it, either by gravity or by a pump, until the tank is empty. It is frequently possible to reduce the screenings from a 24-hour run in one day-shift only.

11. For most economical operation, the material leaving the refiner should consist of, approximately, 75% of material that has been reduced to the desired size and of 25% that is still too coarse. These two classes of materials are separated in a small screen, and the coarser lot is returned to the refiner for further treatment. The accepted material is run to a small wet machine, and is taken off in laps for shipment; or, it is stored for making board or wrapping paper.

The chief claim of this machine (the ball mill refiner) in the pulp industry is its applicability to chemical-pulp screenings. Under average conditions, the machine will handle in 24 hours, 5 tons, dry weight, of chemical-pulp screenings, reducing them to a size acceptable by a 20-cut flat screen. The resulting product contains all the strength of the original fibers, since the action of the round, smooth pebbles is one of brushing and rubbing rather than one of cutting the clusters into small pieces. Knots and slivers are broken apart. The stock thus produced is used with other groundwood and sulphite in the manufacture of newsprint or wrapping paper; the coarse, partially refined material remaining is used for certain grades of wrapping papers and boards.

This refiner takes about 25 h.p. when running at maximum capacity; there is practically a constant load, regardless of the amount of material fed, and the refiner cannot be forced to use excessive power. An occasional inspection and oiling and an adjustment of the feed and water supply, is the only labor attendance required.

12. Disk Type.—There are on the market several makes of the type of refiner shown in Fig. 3. The principal parts are the stationary stone *A* and the rotating stone *B*, between the carefully cut surfaces of which, the stock is fed through the opening *C* at the center of the stationary stone. The rotating stone is carried on the shaft *E*, driven by a belt or motor. The refiner is fed with knots or screenings, which have a consistency of approximately 3%; and as these are rubbed between the surfaces of the stones, the stock works its way to the outer edge, is delivered through the outlet *F*, and drops into a channel that carries it back to the screens, where the fibers that have been sufficiently

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refined are separated. The over sizes again come back to the refiner, until they are properly reduced.

One of these machines, with stones 59 inches in diameter and running at 250–300 r.p.m., will handle the rejections from 40 tons of pulp per day; other sizes will handle proportionate amounts. The horsepower required for operation depends upon the rejections—coarse ground pulp requiring more refining. From 60–80 h.p. may be taken as the average for a refiner of this size.

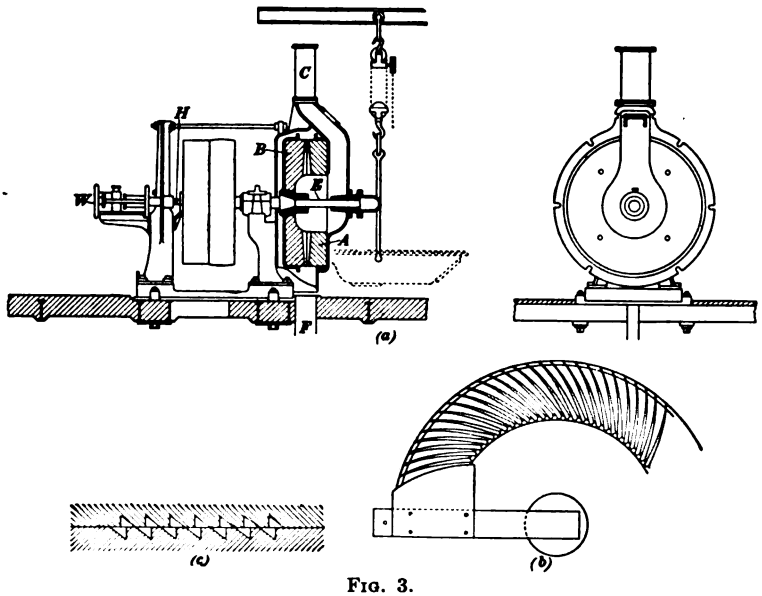

Fig. 3.

When operating this type of refiner, it is particularly important that the grinding surface of the stones be kept in good condition. This necessitates careful dressing and careful selection of the stones.

The pressure of the runner stone against the stationary stone is effected and regulated by means of an adjustable spring *H*, which pushes against a ball bearing at the end of the shaft, and the hand wheel *W*. The stones are enclosed in a cast-iron housing, which permits their easy removal, for replacing with freshly-cut spare stones. The dotted lines in the illustration show the case opened for changing the stone, which is handled by the trolley and chain falls.

A partial plan view of the cut surface of a stone is shown in Fig. 3(*b*), and Fig. 3(*c*) shows a section through the cuts (teeth)

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near the inner edge of the acting surface. When the stones have been carefully centered, they are firmly fastened in place by pouring molten sulphur between the stone and the shell.

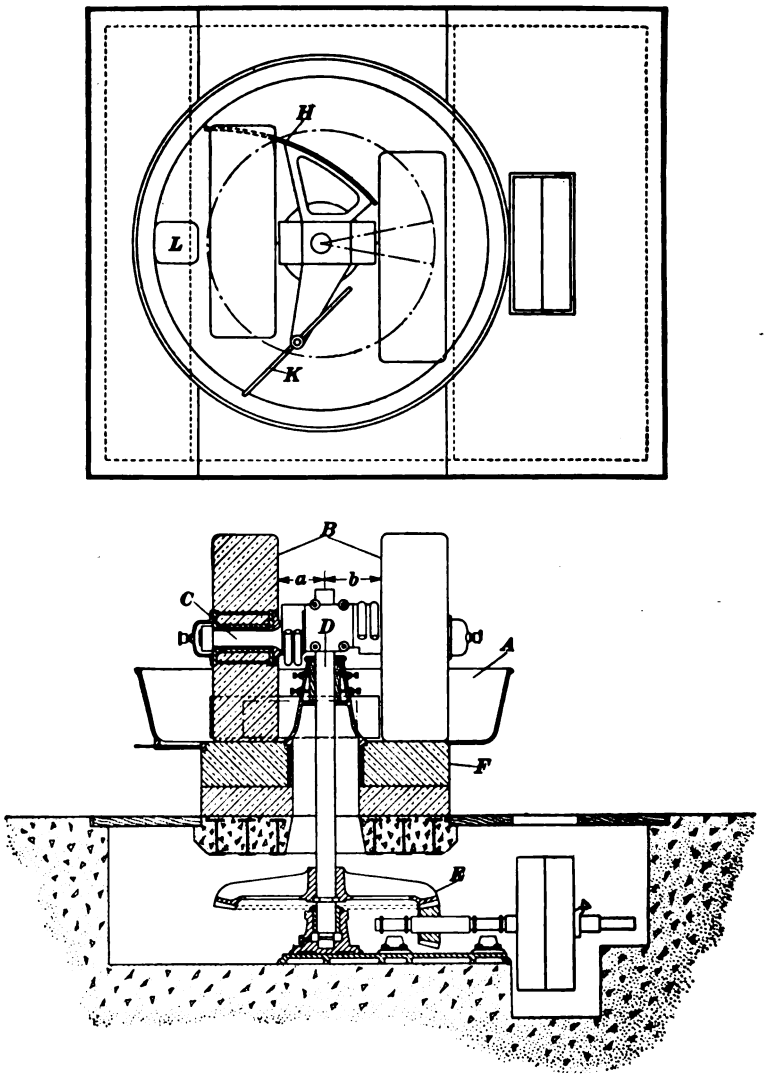

FIG. 4.

13. The Kollergang.—The **kollergang,** also known as the **edge runner** and the **crazy chase,** is shown in Fig. 4. This consists

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essentially of the pan *A* and rolls *B*. The rolls are carried on horizontal shafts *C*, which are caused to revolve in a horizontal plane by applying power to the shaft *D*, through the bevel gears *E*. The portion of the pan that serves as a grinding surface is a stone ring (**bed stone**) *F*, over which the rolls travel; and between the rolls and the ring, the fibers are rubbed and crushed. The action may be intermittent or continuous; modern practice favors the latter; where the operation is intermittent, a charge consisting of about 1000 pounds of screenings and knots, at about 8%. consistency, is fed into the pan, and is treated until the whole mass is finished. This, of course, results in some unnecessary treatment of a portion of the fibers, but it brings the entire mass to a fairly uniform condition. A scraper *H*, which follows one of the rolls, serves to guide back to the grinding zone any stock that tends to spread out to the edge of the pan. When the grinding is complete, another scraper *K* is lowered; this pushes the stock off to the side of the pan, where it falls through the opening *L*, which is then opened for discharging. It will be noticed that the rolls are not hung on a rigid shaft, but on a shaft of special design, which permits the stone to rise when passing over a knot or a bunch of fibers, and also accommodates the machine to the wear of the stones. The distances *a* and *b* from the axis of the shaft *D* to the inside surfaces of the rolls may be different, thus causing the two rolls to travel at different speeds. Note that if the stones have a cylindrical surface, there must be some slip between the stones and the plate; this can be compensated for by cutting the surface to the shape of a cone or by tilting the rubbing plate in the pan.

A kollergang with bed stone 9 feet in diameter and with roll stones 72 inches in diameter and 18 and 21 inches face (one wide and the other narrow), will handle, approximately, 6 tons of chemical pulp per day of 24 hours, and will require about 9–10 h.p. to operate it. The spindle revolves at the rate of 10 r.p.m. It is claimed for one make of this machine that 1000 pounds of pulp is prepared in 50 to 70 minutes.

14. Stone Roll Beater.—In the treatment of mill waste, such as groundwood screenings, splinters, and slivers, sulphite and sulphate screenings, and knots, as well as other mill rejections, the **stone roll beater,** one example of which is shown in Fig. 5, has proved quite effective. It is fitted with a washing drum (water extractor) when desired. The apparatus is built in vari-

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ous sizes, to meet the demands of large and small mills; it is always open to the view of the operator.

A refiner of about 2300 pounds capacity, dry, for each charge of 7% consistency requires only about 80 h.p. for an output of 12 to 14 tons of refined pulp per 24 hours; this is equivalent to about 6 h.p. daily per ton of pulp. It is possible, with this machine, to obtain refined screenings superior in strength to the accepted stock from the first screening.

The screenings, etc., and water, are run into the tub *T*, which is an elliptically shaped trough, and which surrounds the parti-

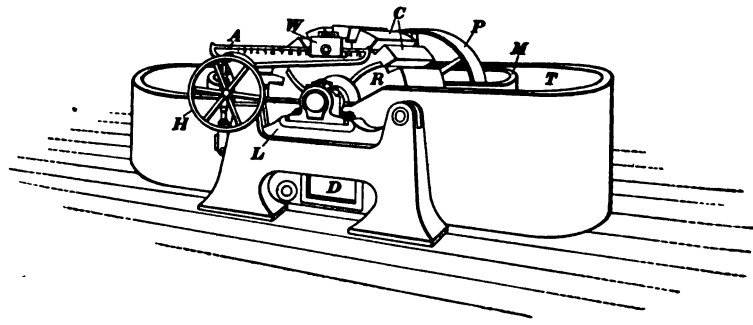

FIG. 5.

tion, or midfeather, *M*. The roll *R*, the surface of which is a set of stone blades *C*, and which is covered by a hood (not shown) is hung on a shaft that is driven by pulley *P*. The stock is introduced at *T;* and as the roll turns, the roll drives the stock between it and the bedplate of stone at *D*. This action not only rubs the fibers but it also causes circulation of stock in the trough. The distance between the roll and the bedplate is controlled by the levers *L* (one at each end of the roll shaft), which are raised and lowered by the hand wheel *H*. The weight of the roll on the fiber is relieved as desired by moving counterpoise weight *W* along the lever arm *A*, which has a tendency to lift the lever (lighter) *L*.

15. Jordan Type.—This type of refiner, which is the one first used and the one still employed most extensively for the final brushing out of fiber-stock previously prepared for the paper machine, has been successfully adapted to the refining of screenings in the pulp mill. The principle in either case is the same, namely: a conical plug *A*, Fig. 6, rotates in a conical shell *C;* the outside of the plug and the inside of the shell are furnished

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with bars or knives *B*, cast in one piece with the plug, and held in place by wooden filling and metal ribs in the shell. The plug bars (and shell bars) are arranged in groups of four parallel bars to each group. The bars are off center (that is, they do not coincide in direction with an element of the cone), and each group makes an angle of about 10° with the next group. The stock, at a consistency of about 3%, enters at *D*, and the large fibers, slivers, etc., are reduced by being rubbed between the plug and the shell. The pressure on the fibers, and, consequently,

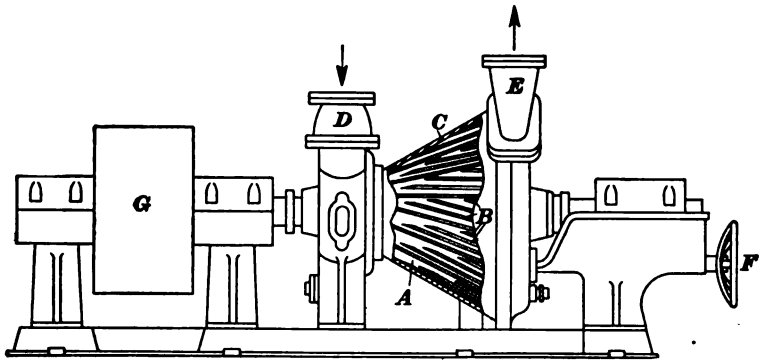

FIG. 6.

the severity of the treatment, is regulated by means of the hand wheel *F*, which moves the plug in or out. The angle of the cone forming the plug is much more obtuse (blunt) than in the ordinary Jordan engine, and the power requirements are thereby reduced.

These refiners are installed most frequently for preparing stock that requires severe beating treatment, as in the case of kraft stock that is intended for the manufacture of high-grade bag and wrapping paper.

The speed of this refiner is about 400 r.p.m., and about 100 h.p. is required for the work that it usually has to perform. The output of this refiner compares favorably with those previously described.

16. Miscellaneous Types.—A type recently developed, which is a sort of centrifugal kollergang, is shown in Fig. 7. The basic principle underlying the design of this machine is old; it combines the effects of hammering of the ancient papermaker and the crushing of the kollergang. It is continuous and automatic in

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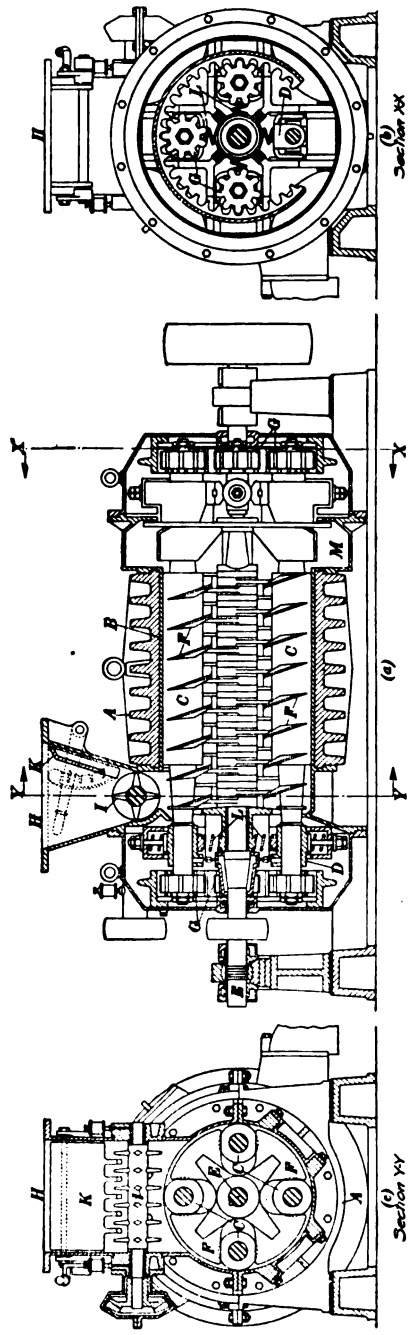

Fig. 7.

operation, with the consequent elimination of an attendant. The machine is constructed of such material that the ordinary machine shop can repair the working parts or make new ones.

The machine consists chiefly of a stationary, cylindrical shell *A*, which has an interchangeable steel lining *B*. The journals of the four (4) rolls *C* inside the shell are located in guide bearings *D*, which are secured to the shaft *E* in such manner that the rolls are free to move out in a radial direction, but must rotate with the shaft. Vanes *F*, which are likewise fastened to the shaft, perform a duty similar to that of the scrapers in a kollergang, and serve to convey the stock through the machine and discharge it at *M*. When the machine is working, the rolls rotate with the shaft and roll over the slivers or stock, with a pressure produced by their centrifugal force. The stock works through the machine in a definite course, and it is crushed a definite number of times. Although the frictional contact between the rolls and the shell is great enough,

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under ordinary circumstances, to cause the roll to turn, an internal gear drive *G* insures their rotation at all times. The inlet *H* contains a small breaker roll *I*, which breaks up any lumps in the supply and keeps any large solid pieces of foreign material from entering the machine. A gate *K*, engaging the breaker roll, allows an adjustment of the feed. If, for some reason, the refiner should stop, the feed roll will also stop (since it is driven from the main shafts), and this prevents plugging of the machine, in case the supply were not shut off.

The crushing pressure between the rolls and the shell may be readily altered by changing the speed or weight of the rolls. The action of the machine responds immediately to varying consistencies of the supply; hence, the quality of the refined stock may be changed at will, and within wide limits, during the operation of the machine; all that is necessary is to change the position of a weight on a lever that controls the water-extracting apparatus. According to one user, the discharge (unscreened) from the refiner, handling groundwood rejections, closely resembles their regular groundwood in general appearance, characteristics, and sliver content.

The large size, which handles 4–6 tons per 24 hours of groundwood slivers, is ample for a 100-ton mill; and the power consumption, when handling this output, is 10–15 h.p. per ton of refined stock.

17. There are many refiners on the market, but the principles involved in the construction and operation are practically identical with those mentioned in connection with the types of machines herein described.

18. Selecting a Refiner.—The use to which a refiner is to be put in a particular mill largely determines the type of machine that would be selected. The best method of determining the efficiency of any type of machine is to determine what the output is per unit of power during a unit of time; this should be considered in connection with the initial cost and the cost of attendance, operation, and upkeep. New machines are constantly coming out that are claimed to be better than those of previously existing types, and the value of these new machines can be arrived at only by a study of their performance in actual operation. If a refiner will handle all the raw and coarse material and convert it into refined pulp without being so crowded that good

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stock is lost through overflow to the sewer, then the machine is doing efficient work. After it has been proved to be satisfactory from this standpoint, the cost of its operation must be considered. If one type requires one or two men to watch it continuously, while another type will run itself at a lower cost, there is no doubt as to which is the better machine, provided the output and cost is the same for each. Whatever may be said for or against a machine by various authorities, the degree of satisfaction it gives to the individual mill is the final measure of its efficiency.

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REFINING AND TESTING OF PULP

(PART 2)

By MAX CLINE, B. S.

TESTING OF PULP

PHYSICAL TESTS

CONDITIONS AFFECTING TESTS

19. Tests to which Pulp is Subjected.—The tests that are to be made on pulp depend on the kind of pulp that is tested and the manner in which it is to be used; they may be comprised under two heads: physical tests and chemical tests. The **physical tests** include the determination of the amount of dry fiber in a shipment, generally called the **moisture test,** and tests made for freeness, color, dirt, and strength. The **chemical tests** include bleach consumption, ash, resin, acidity, alkalinity, cellulose content, oxycellulose, resistent cellulose, etc.

20. Authority for Methods Described.—The directions and methods described in the following pages are based principally on the work that has been done by the Technical Association of the (American) Pulp and Paper Industry, the Association of American Woodpulp Importers, the Scandinavian Wood Pulp Association, and the Technical Section of the Canadian Pulp & Paper Association. Grateful acknowledgment is made of the generous assistance of the American and Canadian Committees on Standard Methods of Testing, and others.

21. Importance of Moisture Determination.—The determination of moisture is of great economic importance, affecting as it does both buyer and seller; it has also a marked effect on the

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freight charges. Although the subject has been widely investigated, the problem has not as yet been completely solved.

At the very outset, it may be stated that accuracy in sampling is of extreme importance, and the accuracy of the results obtained in sampling depends more upon taking a sufficient number of samples from individual units, to insure a fair average of the lot, whether the units are bales or laps, than upon any particular method of cutting the samples.

22. Conditions under which Pulp is Presented for Test.—Wood pulp is presented for test under such a variety of conditions and in so many different forms that no one method of sampling and testing can be made to apply to all forms, and intelligent consideration must be given to local conditions. For instance, the strip method of sampling, while well suited to mill sampling, cannot be applied to frozen lap pulp at receiving points. Again, the auger method, while well adapted to the sampling of baled pulp, is not suited to the sampling of very wet lap pulp. Neither is the wedge method, nor any method that involves the breaking open of the bales, suitable for referee sampling of pulp at the dock, as transportation companies refuse to handle broken bales that have not been so re-baled that they will be in the same condition as when offered at the point of shipment, which cannot be done with ordinary hand presses. The various methods used for sampling pulp are described in detail in succeeding pages.

23. Forms in which Pulp is Shipped.—The following are the commercial forms in which pulp is shipped: (*a*) loose lap pulp, which includes wet laps and hydraulic-pressed laps; (*b*) roll pulp; (*c*) Rogers wet-machine pulp in sheets; (*d*) baled pulp; (*e*) dried sheets; (*f*) hydraulic-pressed pulp, both folded laps and in Rogers wet-machine sheets.

24. Conditions Affecting Official Tests.—The official testing of pulp is governed to a greater or less extent by the place where the test is made, by the time, and by the quantity of pulp tested, and may be summarized thus:

Place: (*a*) at mill during manufacture; (*b*) in transit, as, for example, at dock during transfer from car to ship, for export or vice versa; (*c*) at receiving point, which includes incoming car lots and incoming ship loads.

Time: (*a*) freshly made pulp; (*b*) stored pulp.

Quantity: (*a*) warehouse pulp; (*b*) open piles.

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Whenever possible, the shipment should be kept intact, in all cases of dispute; and in no case, should less than 50% of the lot be presented for test.

25. Determination of Shipping Weight of Pulp.—Since all pulp is invoiced on the basis of air-dry fiber (see Art. **49**), rules for the determination of the wet weight of the pulp are just as important as rules for sampling and testing; but it is necessary in all cases to use judgment in following them. The wet weight should always be determined by one of the following methods:

(*a*) Railroad weight of the entire car lot, where tare of empty car is actually found by weighing. This does not mean the routine railroad weight on the bill of lading, but actual weighing on railroad scales, the weighing being supervised by the party or parties interested in the shipment.

(*b*) Weight of entire car lot as certified by an official, recognized Weighing Bureau, one issuing weighmaster's certificate of weight.

(*c*) Wet weight of lot obtained by finding sum of weights of pulp on trucks passing over accurate, tested scales during loading or unloading.

(*d*) Wet weight of lot may also be determined, where total shipment cannot be weighed, by multiplying the actual number of bales or rolls (as found by accurate count) by the average weight of at least 5% (preferably 10% or more) of *normal* bales, or the average weight of the 20% of rolls selected for weighing. This method gives a very good check on original weight of shipment.

Only bales and rolls that have been weighed according to one of the above methods should be sampled.

26. Definition of Normal Bale.—A normal bale should be intact and unbroken. Those bales whose weight is 50 pounds or more above or below the mill standard weight are to be regarded as abnormal and rejected. For example, if the standard bale weight is 450 pounds, reject as abnormal those bales exceeding 500 pounds in weight and those weighing less than 400 pounds. With half bales, the limit is 25 pounds over or under the standard. Thus, if the mill standard for half bales is 250 pounds, reject all over 275 pounds and all under 225 pounds. The bales that are accepted under these conditions are **normal bales.**

The importance of selecting normal bales is shown by the following tabulation of moisture tests as affected by heavy and light bales:

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Moisture Tests by G. H. Gemmell, in *Paper*, Nov. 3, 1920.

	Light Bales (Under 364 lb.)	Heavy Bales (over 364 lb.)
Number of bales sampled	50	75
Average weight per bale	352.68 lb.	378.08 lb.
Per cent. of air-dry pulp	60.10%	55.70%
Air-dry pulp per bale	211.9 lb.	210.6 lb.

27. Accuracy of Scales for Wet Weight of Pulp.—Scales will be accepted as accurate when they fulfill any one of the following conditions: (*a*) when bearing current seal of the official sealer of weights and measures; (*b*) when verified by comparative weighings with scales of accepted accuracy, for example, scales used for weighing paper for shipment; (*c*) when verified by standard test weights; (*d*) when verified by weighing a known or measured volume of water.

SAMPLING

28. Strip Method A.—This is a method of sampling at the mill, during manufacture; it is suitable: (*a*) for pulp coming from the wet machine; (*b*) for pulp coming from the pulp drying machine in a continuous web.

Details.—Cut a 2-inch or 3-inch strip across entire width of web. On wet-machine pulp, take one sample as just directed for every 2000 pounds of production; on machine-dried pulp, take one sample from, at the very least, every fifth bale or roll of production.

It is to be noted that where this method is applied to dried pulp, the weight of shipping units (wet) is to be taken at substantially the same time as sampling for moisture test. In case pulp is stored at mill before shipment, the shipping units—laps, rolls, or bales—are to be subject to methods of sampling that apply to pulp in these various forms. The wet weight of the lot *must* be determined at the time of sampling.

29. Strip Method B.—This is a method of sampling at the receiving point; it is suitable: (*a*) for pulp coming from the Rogers wet machine; (*b*) for unpressed lap pulp; (*c*) for roll pulp.

Details.—(*a*) For pulp coming from Rogers wet machine, cut 2-inch or 3-inch strip through center of sheet, alternating with direction of sheet and across it; the sampling should be at regular intervals through the lot, and the weight of the wet samples

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should be at least 2 kilograms (about 4.4 pounds) per standard 30-ton car load; 30 or 40 samples will be taken.

(*b*) For unpressed lap pulp, take a 2-inch strip through center of lap, alternating long way and short way of lap; cut half way through lap. The sampling should be continuous through the car lot, and the weight of the wet samples should be at least 2 kilograms per standard 30-ton car load.

(*c*) For roll pulp, take one test strip, 3 inches in width, across the face of the roll from second outside layer, and take four (4) similar strips from layers located at least 1½ inches or farther from outside layer.

30. Accuracy of Method.—Supporting evidence of the accuracy of these methods is given in the report of Technical Section, Canadian Pulp & Paper Association, 1919.

While the strip method is quite commonly used for sampling hydraulic-pressed lap pulp, this method is known to, and has been proved to, give high results on mechanical wood pulp, both by comparing the ratio of wet edge to dry center of sample with the ratio of wet edge to dry center of total lap, and by repeated actual tests that compared the sample taken as instructed above with moisture tests on the whole lap.

31. Auger Method of Sampling Pulp.—The auger method is suitable for sampling: (*a*) baled pulp in sheets; (*b*) baled hydraulic-pressed laps; (*c*) rolled pulp.

It will be convenient to treat (*a*) and (*b*) together, as baled pulp; (*c*) is treated in Art. **38** as rolled pulp.

32. Sampling Baled Pulp.—The sample is to be taken by boring into a bale to a depth of 3 inches (7.62 centimeters) with a special auger (described below) that cuts a disk about 4 inches (10.16 centimeters) in diameter. (It is claimed by some that disks as small as 1⅜ inches in diameter give accurate results.) The disks are removed, and 10 of them are taken for a sample. The disks are selected as follows:

1 disk from second sheet from wrapper
2 disks, beginning at depth of 1 inch (2.54 cm.)
3 disks, beginning at depth of 2 inches (5.08 cm.)
4 disks, beginning at depth of 3 inches (7.62 cm.)
10 disks

33. Location of Borings.—The holes to be bored should be so located that if 5 successive bales were placed on top of one another

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to form a regular pile, the line of centers of the holes will correspond in direction and position with a diagonal of the bales (see Fig. 8), each bale being bored with only one hole. Hole *A* is to be bored at one corner, the edge of the hole being 1 inch from the edges of the bale. The hole in the second bale, indicated by *B* in Fig. 8, is to be bored half way between the first hole and the center of the bale. The hole in the third bale, indicated by *C*, is bored at the center of the bale; that in the fourth bale, indicated by *D*, is to be half way between the center and the hole *E* in the corner; that in the fifth bale, indicated by *E*, is to be again in the corner, and its edge is to be 1 inch from each edge of the bale. This arrangement brings the line of centers of the holes into coincidence with the diagonal of the bales.

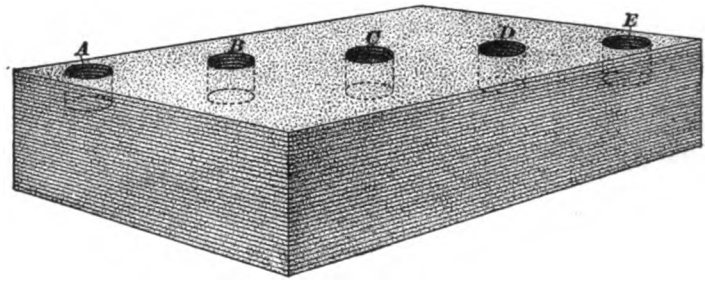

FIG. 8.

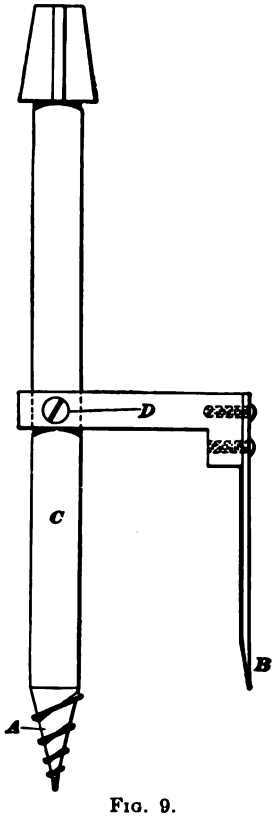

FIG. 9.

34. The Auger and Its Use.—In Fig. 9 is shown a common type of auger used for sampling pulp; it fits an ordinary bit brace or auger handle. The screw *A* draws into the bale, while the blade *B* (which should be curved to a circular arc) cuts disks from the pulp. The blade *B* should be parallel to the shank *C* and may also be adjustable (by screw *D*) along the shank, to allow for wear of the blade.

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35. An improved (patented) auger is shown in section in Fig. 10. Here *A* is a cylinder of saw steel, with a scalloped (serrated) cutting edge *D*, which is chiselled on the inside, to prevent binding. The cylinder is fastened to the head *E*, to which the handles *H* are also attached. The plunger *B*, which is used to push out the sample (disk), has on one side a stud *C*, which tends to turn (bend) the sample downward into an inclined position, to assist in expelling it from the hole. The tool is held vertically, the

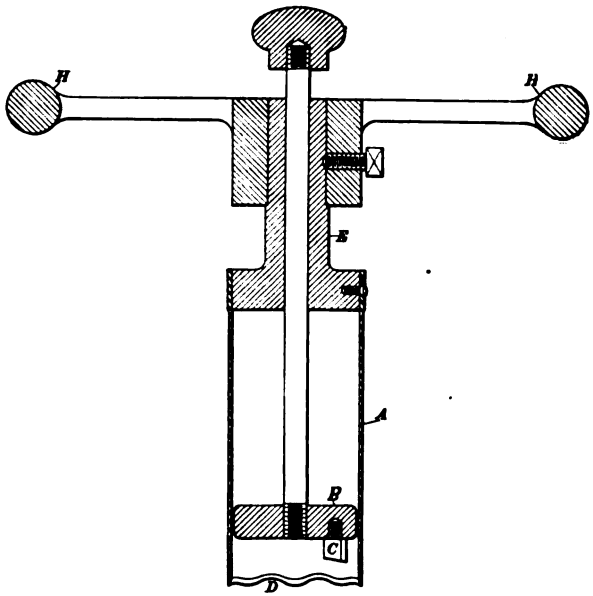

FIG. 10.

surface at which it enters being horizontal. Although, if necessary, the bales, rolls, or laps may be cut in any position, they are most readily cut when the operator can press vertically downward while grasping the handles and turning them, keeping both arms straight or nearly so. Care must be taken in sampling wet pulp that moisture is not pressed out when cutting.

36. Procedure for Very Wet and for Frozen Pulp.—The above method (auger method) is not suited to frozen pulp or pulp containing a considerable amount of moisture, more than 60% or 65%, since difficulty may be experienced, in the latter case, in using the auger, as some of the moisture may be pressed out and lost. For such pulp, the following method may be used:

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Sample bales are taken from the shipment, to the number and in the manner described in the preceding method. As soon as the sample bales have been accurately weighed, a lap is taken from each bale or bundle, at a lower depth from each succeeding package, and a 2-inch strip is cut across the lap, parallel to the width of the wet machine. To do this, the lap or bundle is unfolded, laid out flat, and the strip is cut the full length, near the middle, and including every layer of pulp, so as to include the full width of the sheet, which is cut from one smooth (deckle) edge to the other. A sharp shirt-cutter's knife is most convenient to use for cutting these strips. In the case of frozen pulp, samples are taken most conveniently by sawing them out with a buzz saw. Where these methods cannot be applied, the operator must use his best judgment to secure correct samples.

37. Number of Bales Sampled.—The number of bales sampled should be not less than 5% or more than 10% of the entire shipment, but not less than 10 bales. The samples are to be drawn only from sound and intact bales, selected from the entire shipment; and the person doing the sampling should be careful in observing that no unusual conditions prevail in the selection of the bales.

38. Sampling Rolled Pulp.—Not less, preferably more, than 10% of the lot should be tested. When possible to determine it, the same proportion of outside rolls to center rolls should be maintained during the test as was the case when they came from the machine; that is, if the web is cut into three strips, there are two outside rolls and one inside roll, and *two* outside rolls should be tested for every *one* inside roll. The reason for this precaution is that the outside rolls are generally drier than the inside rolls, and sometimes one side is wetter than the other, due to varying weights on the compound levers at the presses.

39. Location of Borings.—The edge of the first hole is to be 2 inches from the one end of the first roll; the holes in the succeeding rolls are each 4 inches from location of edge of the last preceding boring, traveling toward the opposite end on the roll, and each roll is bored but once. The disks may be selected in accordance with the directions for boring bales, given above; or, the second disk from outside and four others, taken at least

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1½ inches from outside of roll, may be selected, as directed in connection with the strip method.

40. Wedge Method of Sampling Pulp.—The wedge method of sampling pulp is suitable for: (*a*) lap pulp; (*b*) hydraulic-pressed lap or sheet pulp.

41. Arranging and Marking the Sheets.—The wedge, or British, method is carried out as follows:

Bales or bundles are selected as in the preceding methods, and the samples are arranged in groups of six (6) in the following manner. Five (5) sheets are selected from each bale at regular intervals throughout the depth of the bale. The position of these sheets is found by means of a graduated stick (gauge), which is equal in length to the average height of the

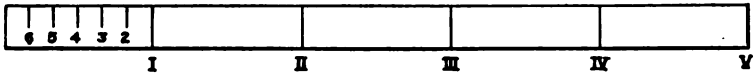

FIG. 11.

bale, and which is divided into five (5) equal parts, numbered from I to V, as shown in Fig. 11. The first space is subdivided into six (6) equal parts, which are numbered from 1 to 6, but in a direction opposite to the other numbers. Now set the gauge (holding it perpendicular to the top surface of the bale) with division I level with the top of the first bale; select 5 sheets from this bale, the first sheet being the top sheet and the others being those opposite the marks II, III, etc. The position of these sheets is clearly indicated in a conventional manner in (1), Fig. 12. Next set the gauge with division 2 on level with the top of the second bale and remove the sheets that are opposite each of the five marks I-V; this position of the gauge is indicated in (2), Fig. 12. Set division 3 of the gauge level with the top of the third bale, see (3), Fig. 12, and remove one sheet opposite each of the five marks I-V. Proceeding in this manner, five sheets are taken from each of the six bales, 30 sheets in all, and each sheet is taken from a different depth, the result being a representative sampling. The sheets to be removed are conveniently identified by marking them with an indelible pencil or a piece of colored chalk, the marks being placed opposite the I-V marks on the gauge. In Fig. 12, the positions of these sheets are indicated by heavy lines, and it will be noted that

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every line is at a different distance from the bottom (or top) of each of the six bales.

When the sheets are removed, they should be covered, and in all handling, care should be taken to prevent change of moisture content, which is caused by exposure, particularly to drafts.

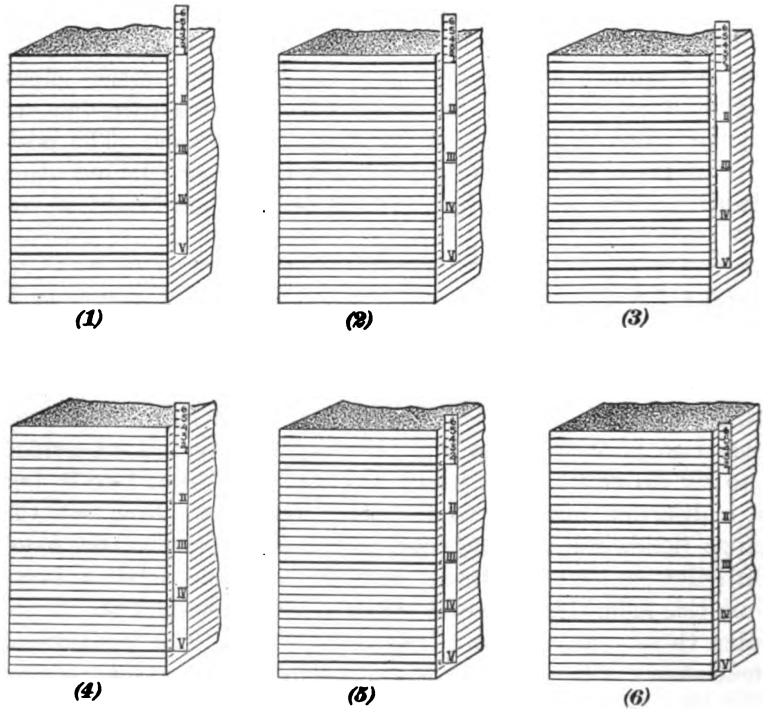

FIG. 12.

42. Locating and Cutting the Wedges.—The sheets being taken as described in Art. **41,** they are sampled, in turn, by using a special template, Fig. 13, which consists of a disk and a rotating wedge-shaped arm. The disk is divided by long lines into 5 equal spaces (arcs), corresponding to the five sheets taken from each bale, and the arcs are subdivided into 6 equal parts, corresponding to the number of bales (6); the circle is thus divided into 30 equal sectors, with angles of 12°. To use the instrument, place it on a sheet of pulp, with the center of the disk exactly over the center of the sheet and with the arrowhead

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on the disk pointing exactly toward the middle point of one edge (preferably the lower edge, but always the *same* edge) of the sheet. To do this, locate and mark the middle point *b* of one edge, swing arm until the edge *a* passes through point *b*, and (holding arm stationary) turn disk until the line carrying the arrowhead coincides with the edge *a* of the arm. With the arm in this position and using edges *a* and *c* for guides, draw lines 1 and 2 on the sheet. Place the instrument on the second sheet in exactly the same manner as before, and draw line 2; revolve arm until edge *a* coincides with line 2, and draw line 3 along edge *c*. Place instrument on sheet 3 in exactly the same manner as before, revolve arm until edge *a* coincides with division 3, arc I, on disk, and draw lines along edges *a* and *c* on arm; these lines correspond to lines 3 and 4. Proceed in this manner with all the other sheets, the various wedges thus marked out corresponding in their numbers on the disk with the numbers of the sheets as removed from the bales. Thus, the fifth sheet of bale IV may be marked IV-5; to set the arm in correct position for the wedge for this sheet, set it first as for the first wedge above described (sheet I-1), revolve it in either direction until edge *a* coincides with division line 5, arc IV, of the disk, and draw lines along edges *a* and *c*. As soon as the outline of the wedge has been drawn on any sheet, the template is removed, and the wedge is cut out from outer edge to the center, care being taken to preserve the point. Another method of locating the wedges is shown in Fig. 14.

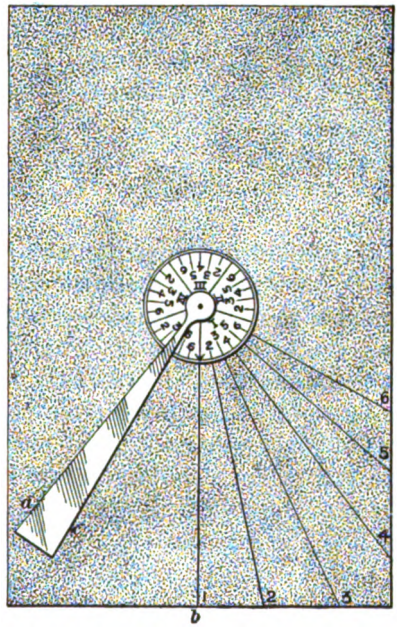

FIG. 13.

43. Accuracy of Wedge Method.—This method is admitted to be accurate when all details are carried out exactly, and when the edges are wetter than the center of the lap or sheet. The

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principal objection to its adoption as the *only* standard is that, in practice, it is difficult to get non-technical men to space the cuts accurately in so many divisions around successive laps. A series of the 30 samples, when put together in their regular order, should form one complete lap or sheet.

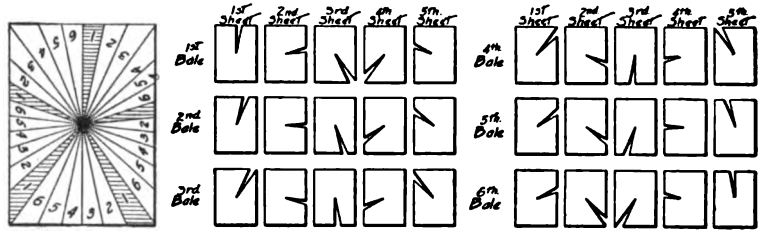

FIG. 14.

44. Modified Wedge Method.—As an alternative to the foregoing, the following modified wedge method is recommended; it has been proved by experience to give results well within the practical limits of accuracy. The wedge is smaller than that used in the other method, the angle being exactly 9°, instead of 360° ÷ 30 = 12°. The wedge sample is cut out from every 100th lap, as piled loose in the car; the wedge extends to the center of the lap, taking care not to lose tip of wedge when cutting out; the cut extends half through the lap; and the cuts are taken from each of the four edges in rotation.

From a 30-ton car, 24 laps should be taken for an average test, and wedge samples should be cut from these. If more samples are desired, extra laps, in multiples of 4, should be taken. The positions of the wedges cut from 4 successive laps are shown at 1, 2, 3, and 4, Fig. 15.

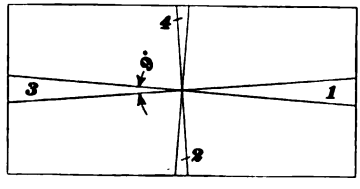

FIG. 15.

For further details of the wedge method of sampling pulp, and for a thorough discussion of the entire subject of testing for moisture in pulp, the reader is referred to that very interesting work, The Testing of Wood Pulp, by Sindall & Bacon. London: Marchant Singer & Co.

45. Care of Wet Samples.—All samples are to be weighed by accurate scales immediately after being drawn from the bales; or, if this is not practicable, the samples must be placed in air-

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tight vessels, made of metal or glass and fitted with metal or ground-glass stoppers; and due care must be taken in the transportation of such samples, until they can be properly weighed. The entire bulk of samples selected from the bales must be weighed and dried out for the test.

46. Sample Can.—A good sample can, especially adapted to caring for small samples, as when an auger is used, consists of a heavy, galvanized outer can, having a hinged cover and a rubber gasket, and a light inner can, with wire lugs to lift it out. The inner can makes a loose fit in the interior of the heavy outer can, the latter protecting the inner can from injury. The cover is fastened down with staple and hasp, and is locked with a padlock, the key to which is kept in the laboratory. The purpose of the padlock is to prevent tampering with the sample, particularly in those cases that are in dispute.

The samples are inserted into the inner can through a narrow slot in the cover. Directly under the slot, and held against the cover by a light hinge and a helical spring, is a thin, metal shutter, which keeps the opening closed, except when the sample is being inserted through it. In case of unavoidable delay between time of taking samples and weighing them, special precaution should be taken to seal the edges of the cover air-tight, with friction tape or otherwise.

47. Weighing Samples.—Both the wet weight and the dry weight should be obtained on the same scales, and with the same weights. Hot dry samples should not be exposed to the air when weighing, since the pulp rapidly absorbs moisture from the air.

Scales used for weighing pulp samples must show a sensibility of .1% (= $\frac{1}{1000}$th) of the maximum load weighed. For example, if 1 kilogram of pulp samples are to be weighed, the scales must show a decided deflection when balanced to this load and 1 gram (= 0.001 Kg.) is added to the load.

48. Drying Samples.—After weighing the wet samples, they should be placed in a suitable oven and dried at 100°C., or 212°F., to constant weight. The maximum allowable variation, plus or minus, from this temperature is not to exceed 5°C. (9°F.); that is, the temperature must not be less than 95°C. nor more than 105°C. (203°F. or 221°F.). Work done below 100°C. (212°F.) is likely to be unreliable, due to the excessive time

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required for complete drying. For the final determination of dryness, two successive weighings should not show a variation greater than .1% of wet weight of samples, and the minimum of these weighings is to be taken as the final bone-dry weight.

If more rapid drying is desired, the sample should be separated into as many thin layers as is possible without loss of fiber. By suspending the individual layers of pulp on a wire running the width of the oven, or by laying them separately on a wire shelf, the sample can be dried to bone-dry weight in less than 8 hours. Samples cut by boring dry rapidly when placed on edge.

A satisfactory oven can be made at the mill by placing a steam or electrically-heated coil in a box having drying shelves and provided with proper ventilation. Several excellent ovens of correct design are on the market.

49. Calculation of Air-dry Weight.—Since pulp is, by trade custom, sold on a so-called *air-dry basis*, which is on the basis of pulp that contains 10% moisture (water) and 90% of absolutely dry (bone-dry) pulp, it is necessary to find how much pulp that contains 10% of moisture is equivalent to a given weight, say a pound, of the pulp containing the percentage of water found in the sample. To show how this is done, all the figuring necessary in making the test is here given in a special illustrative example, taken from actual mill figures.

Weight of can plus moist sample	1251.6 g.
Weight of can	943.2
Weight of moist sample	308.4 g.
Weight of can plus dry sample	1213.3 g.
Weight of can	943.2
Weight of dry sample	270.1 g.

Dividing the dry weight by the moist weight gives the *per cent of bone-dry pulp*, actual fiber, in the sample.

$270.1 \div 308.4 = .8758$, or 87.58% of absolutely dry (bone-dry) pulp.

$100 - 87.58 = 12.42\%$ moisture in sample.

$87.58 \div .90 = 97.31\%$ air-dry pulp (containing 10% of water) that sample contains. This is correct, because 90% of 97.31%

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of air-dry pulp gives 87.58%, the per cent of bone-dry pulp found in the sample.

If desired, instead of dividing by .90, the same result may be obtained by multiplying by $\frac{1}{.9}$ or its equal, 1.1111.

The purchaser would pay for 97.31 pounds of air-dry pulp for each 100 pounds of pulp showing 12.42% moisture by the above test. Thus, if a car contain 46,280 lb. of this pulp as shipped, it contains 46280 × .9731 = 45,035 lb. of air-dry pulp, which is what the purchaser pays for.

In case of dispute, a re-test that comes within 1% of the original air-dry weight of pulp as invoiced is deemed to uphold the original invoice, the complaint is deemed to have been groundless, and the expense of making the re-test is charged against the party making the complaint.

The practice of buying and selling on the air-dry basis is founded on an arbitrary assumption. It would be more scientific, convenient, and accurate to use the amount of bone-dry pulp in a shipment for making calculations.

DETERMINATION OF CHARACTER OF FIBER

50. Use of Stereopticon.—A small representative portion of pulp is shaken up with water until it is thoroughly disintegrated. A dried or partially dried sample is softened by bringing it to a boil in a 1% caustic soda solution, pouring off the alkali, and washing it free of alkali by several decantations with hot water. It is then vigorously shaken in a bottle, in which glass beads have been placed, until the pulp sample is disintegrated. A representative portion of the disintegrated pulp is then thinned with water, in a bottle, to the proper consistency, so that, when a small portion is carefully poured on a glass slide, the slide will be covered with fiber that is so distributed and separated as to present a uniform field for easy examination, when projected on a screen by means of a projecting lantern. The slide is covered by another similar glass slide, and both are placed in an oven to dry.

51. Examination of Slide.—When dried, the slide is placed in the lantern, alongside a slide made of the standard pulp, which has been similarly prepared, and the images of both slides (one made from the sample and the other from the standard) are thrown on the screen. These images are side by side, and the

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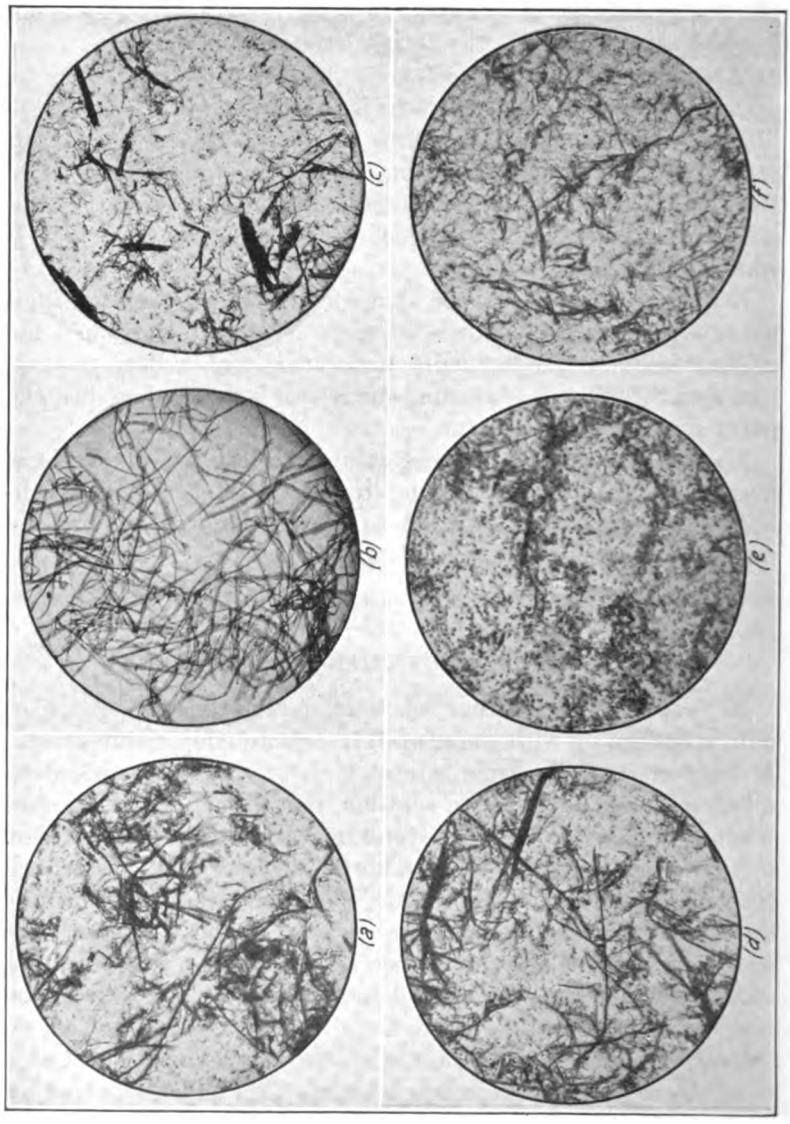

FIG. 16.—(*a*) Mechanical wood pulp, good grade; fibers long and free from coarse particles; very good for news. (*b*) Spruce sulphite pulp of good news quality. (*c*) A short and very coarse mechanical wood pulp; very poor quality. (*d*) A rather coarse mechanical wood pulp. (*e*) Mechanical wood pulp, ground very fine, so that a large proportion has been converted to flour. (*f*) A short, fine-ground wood, suitable for substitution of soda chemical pulp made from hard woods.

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fibers may be compared for length and width. By setting a standard for length and width at an arbitrary value, say 70, the analyst can rate a longer fiber at, say 80, and an extremely long one at, say, 90; a shorter one may be rated at, say, 60, and a very short one at 50. Width or coarseness of fiber is valued in the same manner. While this method lacks the scientific accuracy of true measurement under the microscope, it has the advantage of permitting a rapid observation of a large number of fibers, and a trained analyst can thus test a very large number of samples in a day and obtain a true valuation of the quality of the pulp tested. Mechanical wood pulp, as might be expected, gives greater variation as to length and coarseness of fiber than any other kind of pulp; this will be evident from examination of the six photomicrographs shown in Fig. 16. The circles here reproduced may be ten times as large, or even larger, when thrown on the screen, as those shown in the illustration, depending on the adjustments of the lantern, and the sizes of the fibers will be changed in the same proportion. This procedure has disadvantages, in that the stock assumes a different appearance when dried, and that the sample is very small.

52. Blue-glass Test.—Another test for comparing the length and coarseness of fibers, generally used for a mill-control test

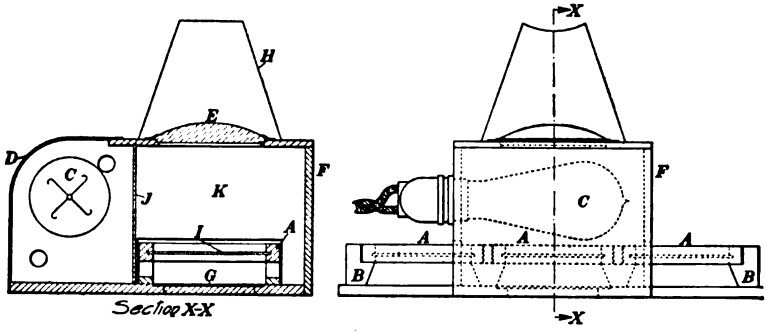

FIG. 17.

for uniformity in the manufacture of ground-wood pulp, is what is known as the blue-glass test, which may be described as follows:

Referring to Fig. 17, the apparatus consists essentially of a frame *B*, which contains three or more trays *A* having clear

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glass bottoms *I*, a box *F* through which the frame slides, an electric light *C*, a tin reflector *D*, a magnifying glass *E*, and a shade *H*. A circular hole, about 3½ inches in diameter, over which the magnifying glass is placed, is cut in the top of the box. Directly underneath this hole, a piece of blue glass *G* is sunk into the bottom of the frame. A piece of ground glass *J* is placed between the light *C* and the examining chamber *K*, for the purpose of diffusing the light from the bulb *C*. To operate, very dilute stock is poured on the glass trays, which are moved along under the magnifying glass. The stock is thus examined in its natural element, water; it is so magnified that its nature is revealed very clearly, and its suitability for use in the formation of a sheet of paper is readily determined. Several samples may be compared with one another or with a standard.

Some mills still use simply a single tray, about 6 inches square, with blue glass for the bottom, without the magnifying glass.

TESTS FOR FREENESS, SEDIMENTATION, AND CLEANNESS

53. Definition of Freeness.—The rate of drainage of water from the sheet through the cylinder mold or Fourdrinier wire, called the **freeness** of the stock, while not a physical property of an individual fiber, is a valuable indication of the *quality* of a mechanical-pulp mixture. It is closely related to the uniformity, strength, and finish of the mechanical pulp, and of the paper made from it.

The freeness tester and the sedimentation tester are the two pieces of apparatus used for laboratory and mill tests of freeness, and will now be described.

54. Sedimentation Tester.—The sedimentation tester, illustrated in Fig. 18, consists of a graduated glass cylinder *A* (graduations run from 0 to 12, the zero (0) mark being 12 inches above the wire disk *B*), 3 to 3¼ inches in diameter and 14 inches long, with ground ends for a joint. A $3\frac{3}{16}$-inch disk *B*, cut out of a Fourdrinier wire, is clamped between the cylinder and a metal cone *C;* a ¼-inch rubber tube *D*, 30 inches long, is attached to the end of the cone, and a pinch clamp *E* is placed on the end of the tube for the purpose of releasing water from the cylinder.

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(It is reported by Millidge that a short tube is cleaner and that it works equally well.)

55. Operation of a Sedimentation Tester.—For testing purposes, stock of about .6% consistency is taken. An accurate test is made for consistency by filtering, say, 100 c.c., and then drying and weighing the fiber. A sample of 1500 c.c., the amount necessary to fill the tester up to the 12-inch mark, is made up to a consistency of .05%; this is well shaken in a 2-liter flask. The apparatus is filled with water, just up to the wire, and the stock is poured rapidly into the cylinder, until it is filled up to the top mark. The short rubber tube is quickly pulled off, and the time, in seconds, required for the stock to fall through a definite distance (for the top level to fall through a definite height) in the cylinder is noted. If the stock is so free that a consistency of .05% gives too fast a flow, the stock may be diluted to .1% bone-dry fiber. As the stock level falls, a fiber mat is formed on the wire, and this mat offers a resistance to the flow of water, which is in direct proportion to the fineness of the stock. The difference between pulps of varying degrees of freeness is determined by finding the difference in the times it takes the stock to run to, say, the 9½ mark. A coarse or free pulp runs down to the mark quickly; a fine or slow pulp runs down slowly. Duplicate samples are always thus tested; on relatively coarse pulp, the difference in time between the two tests is rarely over 2%, and is usually less. This difference increases as the fineness increases; but, in no case, should it exceed 10%; should it do so, the samples are tested over again.

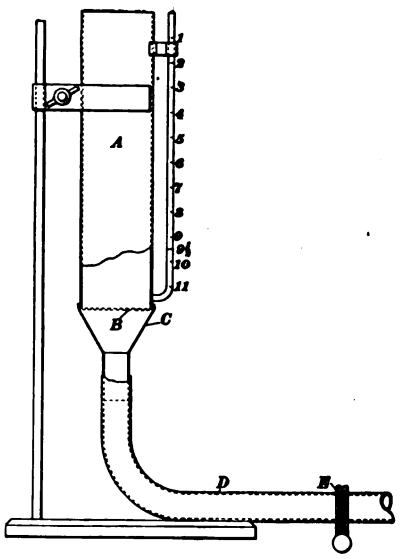

FIG. 18.

The principal value of this test is the indication it gives of the way the pulp will behave on the paper machine. A free pulp will drain quickly on the machine, thus permitting faster running;

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a slow pulp will require either a slower operation of the machine or a more powerful suction, but will give a better formed sheet, due to the filling in by the fibers.

56. Freeness Tester.—A familiar form of freeness tester is shown in Fig. 19. It is made in two main parts: a container *A* for holding the stock while drainage takes place through the fiber mat and wire bottom *B* on which the mat forms; the funnel *C* into which the water passes after being strained through the fiber mat. The funnel has two outlets; one *D*, at the bottom is $\frac{1}{8}$ inch in diameter, while the other *E*, on the side, is $\frac{1}{2}$ inch inside diameter. Since the hole in the bottom is not large enough to pass a large volume of water under a low head, there is an overflow through the side hole *E*, and a graduated cylinder *F* is used to catch this overflow. The volume of water passing through the overflow is a measure of the freeness of the stock, a free stock causing a large overflow and a slow stock causing a smaller overflow. This tester is also adapted to pulp-mill control. (See Section on *Mechanical Pulp*.)

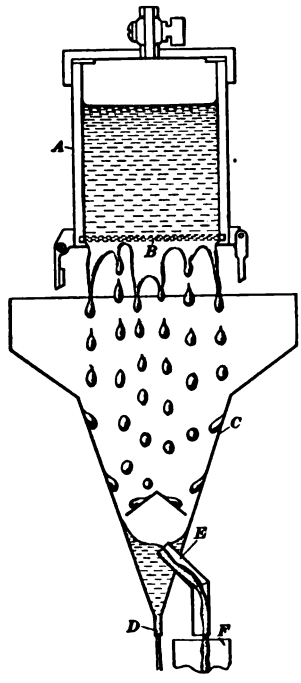

FIG. 19.

57. Operation of Freeness Tester.—About 500 grams of mechanical (groundwood) pulp stock from the deckers or thickeners (equivalent to about 20–25 grams, bone dry) is placed between layers of felt, inserted in a wine press or a letter press, and is pressed firmly, but not too hard. If pressed too hard, time and accuracy are lost in breaking up the pulp, for making the test. The pulp should contain about 50% of moisture. The pressed cake of pulp is rubbed between the hands and mixed thoroughly; 20 grams are weighed on a scale that is sufficiently accurate to weigh to 0.1 gram, and is then dried to determine the bone-dry weight, from which the per cent of bone-dry pulp can be found. The remainder of the pulp is placed in a corked sample bottle.

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The per cent of bone-dry weight is calculated to one decimal place. Having found this, weigh out the amount of pressed pulp that will contain 4 grams of bone-dry pulp, place in a large-mouth, 1-liter bottle, add about 500 c.c. of water, insert cork, and shake until the pulp is thoroughly broken up Pour water into the tester, filling the funnel *C*, Fig. 19, until the water just reaches the wire and the pulp solution; rinse out the bottle and fill the tester *A* to exactly 1000 c.c. This gives a .4% (4 ÷ 1000) consistency, which is practically the same as is used on the paper machines. Stir the solution, screw on cover, and immediately open stop cock. Catch and measure the water that runs from the side tube of the funnel. Rinse out tester thoroughly, and check sample. The number of cubic centimeters of water caught from the side tube is used as a direct comparison of pulp as to freeness. Thus, in applying this test to the beating operation in the paper mill, 120–150 c.c. of water shows that good results are being obtained; 150 c.c. or over shows that the pulp is quite free; while 100 c.c. or under shows that the pulp is quite slow. In the paper mill, the samples are taken at frequent, regular intervals, by the beater engineer.

58. Corrections to be Applied.—In order that the drainage action indicated by either of the two foregoing pieces of apparatus may be representative of the fibers only, it is necessary to correct all observations to: (*a*) a standard consistency of the stock; (*b*) to a standard temperature of the fiber suspension. A standard consistency is necessary because the rate of fiber deposition, and, consequently, the thickness of the felt mat and resistance to drainage action, varies directly with the percentage of fiber per unit of volume of the suspension. The importance of temperature as a factor in testing is shown by the curve in Fig. 20, which indicates how rapidly the rate of flow varies with changes in the temperature of the water; this shows diagrammatically the viscosity variation of water with temperature. It is very evident that the less viscous a fluid is the more easily it will pass through a filtering medium.

Instead of waiting for the determination of dry fiber in the sample, the pulp may be diluted immediately, approximately to the desired consistency, and the test carried out. The freeness is corrected later to standard consistency.

In order that the results from the use of these pieces of apparatus may be reliable, considerable technique must characterize

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their use in control work. Experience has also shown that the results they give are comparable only when they are obtained by the same apparatus and under like conditions; this means that comparisons made in different mills, with differences in apparatus and conditions, are not comparable.

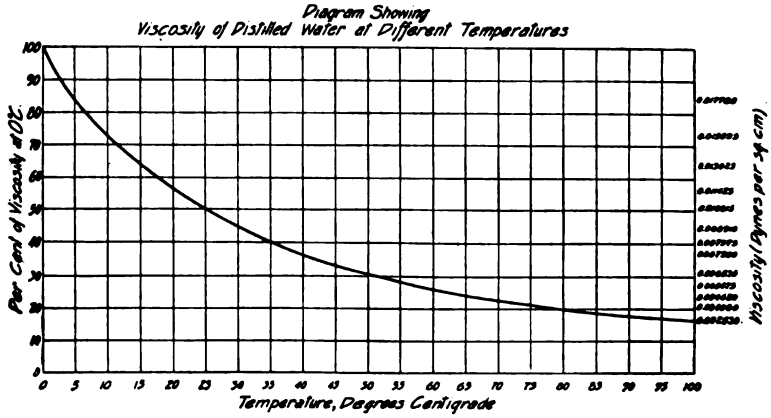
Diagram Showing
Viscosity of Distilled Water at Different Temperatures
Per Cent of Viscosity at 0°
Temperature, Degrees Centigrade

FIG. 20.

59. Cleanness or Screening.—An average sample of the pulp is shaken with water, using glass beads if necessary, until it is thoroughly disintegrated; it is then thinned out to about 1% consistency, and several sheets are made on an ordinary sheet machine. The sheets should be sufficiently thin to permit of examination by transmitted light. The examination is best done by using a set of standards, which consists of a number of sheets of pulp containing varying amounts of shives, fiber bundles, dirt (rust, sand, bark, etc.), from sheets containing but little dirt and no shives to sheets containing a large amount of dirt and shives, the first ranking very high and the second very low. These sheets are mounted on the glass top of a wooden or metal box, into which are fitted a few electric-light bulbs; when the current is turned on, a strong light will be transmitted through the sheets of pulp. The samples to be examined are placed alongside the standards, one after the other, for comparison and grading.

TESTING STRENGTH OF PULP

60. Proposed Standard Method.—Considerable work has been done toward developing a standard method for testing the

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strength of pulp. Edwin Sutermeister has proposed a method —*Paper*, Nov. 10, 1915—which has been modified by the Sulphite Pulp Committee of the Technical Association of the (American) Pulp and Paper Industry, and the latter has been suggested as a standard method for adoption by the T.A.P.P.I.—*Paper*, Nov. 8, 1916. This report gives a detailed and critical description of the method, and it should be carefully studied by all analysts interested in the subject. Briefly, the method is as follows:

An average sample of the pulp is taken, sufficient to give about 380 grams of air-dry fiber. This is thoroughly mixed with enough water in a tub at room temperature to give a volume of 20 liters. By means of a sampling pail that is 3 inches in diameter and 6 inches deep, or with a dipper of the same capacity, this stock is transferred to a disk or sheet machine, where a plaque of pulp, 5 inches in diameter, is produced; the plaque is then removed on a felt disk, which is placed on top of a 5-inch galvanized-iron disk, and pressed, felt side down, upon the pulp. A cheese form that contains from 15 to 16 plaques of pulp, between disks of felt and iron, is built up and is placed under a 10,000-pound concrete block, or under equivalent pressure in a hydraulic or a mechanical press, for five minutes; after which, each plaque is placed in a punch press, and a 4-inch disk is stamped out. The plaques made in this manner contain 60% of bone-dry fiber; that is, 167 grams of pulp from a plaque contains 100 grams of bone-dry fiber. Then 167 grams of this pulp is weighed out and is thoroughly mixed with two (2) liters of water at room temperature; it is then transferred to a small Abbe pebble mill, which has a volume of 16,600 c.c. and is furnished with a charge of pebbles having a volume of 1780 c.c. The mill is revolved at 60 r.p.m. for 50 minutes, and the charge is then dumped into a 10-quart pail, rinsing out the pebble mill. The pebble charge is dumped into a strainer box, set over a tub, and the stock is removed from the pebbles, taking care not to lose any stock. The combined stock is diluted with water to 20 liters, making a stock containing .5% bone-dry fiber. Four (4) sheets of paper are then made, by using a hand mould, 7 by 9 inches is a common size, and are then couched, dried, and pressed in the usual manner, care being taken to make the sheets uniform in size and thickness. The sheets are weighed, cut diagonally from corner to corner, and each half sheet is tested in

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four evenly spaced places along the diagonal line of cutting, using an Ashcroft tester. Since there are 8 half-sheets, and each is tested in 4 places, 32 Ashcroft tests are made on one sample of pulp. The sum of the 32 readings thus obtained divided by twice the weight of the four sheets (since there are 8 half-sheets) gives what is called the **unit weight test** of the sample. Assuming that the sheets tested are always made as just described, that they are always 7 by 9 inches in size, and that the only variation lies in the thickness of the sheets, the weight will be directly proportional to the thickness, *i.e.*, to the cross-sectional area. Since it is a difficult matter to determine accurately the cross-sectional area and it is very easy to find the weight accurately, the weight is used as a factor in the strength instead of the cross-sectional area.

Suppose, for example, that the sum of the 32 tests on one sample is 640 grams and the weight of the 4 sheets is 8.42 grams, then

$$\text{Unit weight test} = \frac{640}{8.42 \times 2} = 38.0$$

The Mullen tester may also be used instead of the Ashcroft tester, and the unit weight test found as just described. However, tests made with one tester must not be compared with those made with the other tester.

By cutting a strip of suitable width, from corner to corner, a test for the tensile strength and for stretch may also be made, using a Schopper or a similar instrument.

It has been found possible to get a sheet of more uniform thickness by using a sheet machine similar to the upper part of the freeness tester, Fig. 18. By keeping the stock well mixed, each sheet contains the same weight of fiber.

Suppose a strip of indefinite length to be suspended so that it hangs freely; there is evidently a certain particular length between the free end and the point of suspension for which the strip will weigh just enough to cause the strip to break under its own weight, which may be represented by W; this length is called the breaking length, which may be represented by L. Let w = the weight of the strip tested and l = its length, then the breaking length L may be found from the formula

$$L = \frac{Wl}{w}$$

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in which the weight W is equal to breaking weight, which may be found by breaking the strip in a testing machine; here l = the length of the strip between the clamps of the machine, and w = the weight of this strip of length l.

TESTING PULP FOR COLOR

61. Testing Color of Bleached Pulp.—A satisfactory method for testing the color of bleached pulp, for mill-control work, has been suggested by the Sulphite Committee of the Technical Association of the (American) Pulp and Paper Industry—*Paper*, Nov. 8, 1916. Briefly, the method consists in attaching six disks of the pulp to the front of six wheels, of varying degrees of whiteness, which are made by pouring into brass wheels different mixtures of plaster of Paris, magnesia, potassium chromate, and water, allowing these to set, and then planing to a smooth surface. The sample disks are a little smaller than the wheels. The wheels are set up in a dark room, which is illuminated by two daylight lamps. The wheels, with the attached pulp disks, are revolved at 2500 r.p.m., and the operator judges to which of the standardized color wheels the pulp is nearest in shade. It may be an advantage, instead of stating which wheel the pulp most nearly matches in shade, to state between which of the standard wheels the pulp shade comes. A set of wheels, as used by one large producer of bleached wood pulp, is given by Sutermeister in the following table:

No. of wheel	Water	Plaster of Paris	Chromate Potash	Magnesia, Powdered,
100	120	107	0.0	20
95	120	107	0.0245	20
90	120	214	0.1490	0
85	120	214	0.4660	0
80	120	214	0.6120	0
75	120	214	0.7770	0

The plaster of Paris and magnesia are first thoroughly mixed together, then the water added, and the paste is thoroughly stirred up and poured into the wheel.

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When pouring the wheels containing the chromate, the latter is first dissolved in the water, the solution added to the plaster of Paris, the whole thoroughly stirred up and poured into the wheel.

After pouring, the wheels are allowed to set forty-eight hours and then revolved by means of the motor, and turned down smooth with a sharp-edged cold chisel, and finished with fine sandpaper.

A sewing machine belt was tried out to drive the machine but a satisfactory fastener could not be found which, at the speed employed, would not pull out after a short time. It was found that $\frac{1}{4}''$ rope with a spliced joint stands up very well.

This method is applicable to mill-control work when but one grade of bleached pulp is made; for testing different bleached pulps by this method, the manufacture and installation of a very large number of these standard brass wheels, filled with the plaster of Paris mixture, would be required.

62. Use of Tintometer.—Another method of determining the color of pulp is by the use of a **tintometer** (tint measurer), which gives a reading of the color in terms of standard red, yellow, and blue glasses. The Lovibond tintometer is an instrument of this character. It consists of a narrow, rectangular box, which is divided into two tubes by a central partition and is hinged at the objective end to a base, so it can be inclined at an angle to suit the observer's convenience. A standard white surface, which is prepared by pressing some pure precipitated calcium sulphate into a tray, is placed at the base of the instrument and opposite one of the tubes; the object to be examined is placed at the base of the instrument and opposite the other tube. The observer looks into and down the tubes of the instrument; he inserts the standard color glasses in the grooves at the end opposite the standard white surface, changing them until the color of one apparently matches that of the object, which is then said to be the same as that of the standard color glass. Variation in the surface of the object makes a difference in the result obtained with this instrument. Furthermore, it is difficult to make the glass standards so they will retain their color values permanently, and to duplicate the glass standards so they will give exactly the same reading. A full discussion of color and color measurement is given in the Section on *Paper Testing*, Vol. V.

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CHEMICAL TESTS

BLEACH CONSUMPTION

63. Method of Procedure.—Macerate 5 grams of the air-dry unbleached pulp in a porcelain mortar, with small quantities of water, until about 50 c.c. of water has been used; the mass is poured into a wide-mouth, glass-stoppered bottle. Add 20 c.c. of a solution containing 5% available chlorine, or an amount sufficient to give an equivalent of bleaching powder slightly in excess of that which the sample appears to require, and add enough water to make a total volume of 125 c.c. Place the bottle containing the pulp and bleach in a pan of water for 3 hours, keeping the temperature of the water at 37°C. (98.6°F.) during this time, and shake the bottle at frequent intervals. Filter the mass on a Büchner funnel, wash until free from chlorine, as indicated by potassium-iodode starch paper, and titrate the filtrate for unconsumed bleach with standard sodium arsenite or sodium thiosulphate. (For procedure, see Section on *Bleaching of Pulp.*) If more than 2% excess of bleach is found in the filtrate, the test should be repeated, with a bleach liquor testing only 1% in excess of that consumed in the previous test.

SOME SPECIAL TESTS

64. Testing for Ash.—Two (2) or more grams of air-dry pulp is carefully weighed and ignited in a platinum or porcelain dish at a low red heat until the carbon is burned off. The weight of the ash divided by the original weight of the pulp and multiplied by 100 gives the per cent of ash. One of the numerous ash balance apparatus that are on the market, which are used for the determination of ash in paper, may be used for this purpose.

65. Testing for Resin.—The same procedure as for the determination of resin (rosin) in paper is applicable to this test. (See Section on *Paper Testing*, Vol. V.) The amount of resin in pulp is of importance, chiefly because of the trouble it may give on the paper machine. This point is briefly discussed in the Sections on *Properties of Pulpwood and Sulphite Pulp.*

66. Testing for Acidity.—Ten (10) grams of air-dry pulp is extracted with 200 c.c. of water at room temperature for 30

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minutes. The mass is thrown on a Büchner funnel, washed until the wash water no longer reacts acid with litmus, and the extract and wash water is titrated with $\frac{N}{100}$ alkali solution, to determine the amount of free acid in the sample, using methyl orange as an indicator. This test is applied to sulphite pulp.

67. Testing for Alkalinity.—The sample of pulp is extracted and washed as described in Art. **66** until it is neutral to litmus, and the extract is titrated with a $\frac{N}{10}$ acid solution, to determine the amount of free alkali in the sample, using methyl orange as an indicator. This test is applied to soda and sulphate pulps.

68. Testing for Cellulose.—Two (2) grams of the bone-dry fiber is boiled in a 0.5% solution of caustic soda for 15 minutes. It is then filtered on a small Büchner funnel that is covered with a filter cloth, to prevent loss of fiber, washed free from alkali, and teased out (i.e., the fibers are separated and spread out) on a watch glass. The watch glass containing the fiber (pulp) is then placed in a bell jar, where it is exposed to the action of chlorine gas for 5 minutes. It is then filtered and washed as before, placed in a 2% solution of sodium sulphite, and brought to a boil. The fiber is filtered and washed as before, placed in a .1% sodium hypochlorite solution (NaClO) for 30 minutes, filtered, washed with water that contains a little sulphurous acid, and then washed with hot distilled water. The fiber is then placed in a weighing bottle and dried to constant weight. The weight thus obtained divided by the weight of the sample and multiplied by 100, is the per cent of cellulose in the pulp.

For further particulars, the reader is referred to the works of Cross and Bevan, Sutermeister, and Johnsen and Hovey.

69. Sulphuric Acid Test.—25 milligrams of air-dry and finely disintegrated pulp is dissolved in 50[1] c.c. of cold, chemically pure, sulphuric acid of 1.84 sp. gr. in a graduated tube having a ground-glass stopper. In a second tube of the same dimensions, a standard pulp is treated in identically the same manner; after thoroughly shaking, the colors of the two solutions are compared, and sulphuric acid is added to the first pulp until the color of the solution matches that of the standard. The total number of

[1] Klason recommends 20 c.c.

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c.c. of sulphuric acid required to obtain the standard color indicates the purity of the pulp.

The test is, of course, only comparative; it does not give the actual percentage of lignin. It is useful in mills where there is no great variation in quality, but it is not recommended for comparison of pulps from different sources.

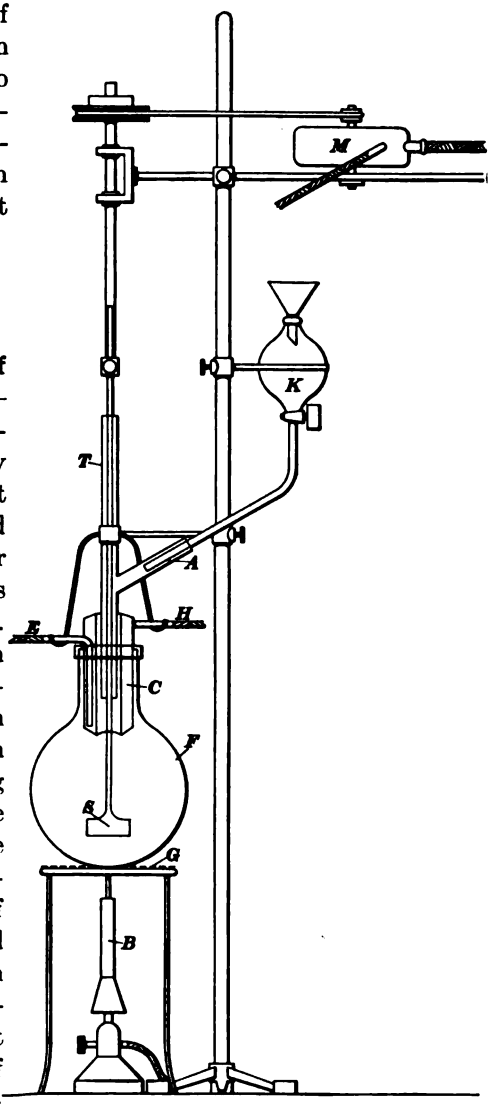

FIG. 21.

OXYCELLULOSE TEST

70. Determination of Copper Figure, Cu. F.— This test for oxycellulose was developed by Schwalbe, and the result obtained by it is called the **copper number** or **copper figure,** sometimes abbreviated to Cu. F. The test depends upon the reduction of the copper in Fehling's solution by aldehydic groups in oxycellulose. Coloring matter and lignin give the same reaction. The results of the tests are expressed as the number of grams of copper reduced from Fehling's solution by 100 grams of bone-dry pulp. The exact structural formulas of these reducing compounds being unknown, it is not possible to obtain any ratio between the oxycellulose content and the normal cellulose content. The test must be

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closely controlled, since Fehling's solution decomposes spontaneously, even while the reducing action is taking place; but this reducing action may be considered to be constant, if the testing routine is always the same.

The apparatus used in this determination is shown in Fig. 21. Here *F* is a 1½-liter (1500 c.c.), round-bottom flask, in the neck of which is suspended the cooler *C*. Cooling water enters at *E* and leaves at *H*. The shank of the glass stirrer *S* passes through the tube *T*, which has a side arm *A*, for introducing material from the separatory funnel *K*. The stirrer may be driven by a small electric or water motor *M*. *B* is a burner, and *G* is a wire gauze, to protect the flask.

Weigh accurately from 2 to 3 grams of air-dry or approximately air-dry pulp, and while the test is under way, determine the moisture content exactly. The pulp must then be reduced to a finely subdivided state. The Fehling's solution, which should be mixed fresh every day, is prepared as follows:

Fehling's Solution.—Solution (1): Weigh out 69.28 grams of pure copper sulphate, and make up to 1 liter with distilled water, after adding 1 c.c. of pure sulphuric acid. Solution (2): 350 grams of Rochelle salts (potassium sodium tartrate, $KNaC_4H_4O_6 \cdot 4H_2O$) is dissolved in about 700 c.c. of distilled water, and a little caustic soda is added to the solution, if not clear; 100 grams of pure caustic soda NaOH is dissolved in 200 c.c. of water and then added to the solution containing the Rochelle salts, and the whole is made up to 1 liter. Equal volumes of solutions (1) and (2), when mixed together, give Fehling's solution as it should be used in this test. A smaller quantity of this solution may be made up, if desired, using the same proportions.

Place the pulp in the flask *F*, Fig. 21 add 250 c.c. of boiling distilled water, and rotate stirrer at about 120 r.p.m. Heat to boiling, separately, 50 c.c. each of solutions (1) and (2) of Fehling's solution, always adding (1) to (2), and introduce into flask by means of funnel *K*; wash all solution into the flask with 50 c.c. of water. Boil exactly 15 minutes. Remove heat, detach flask, and add 50 c.c. of a suspension of 20 grams of infusorial earth in 1 liter of distilled water; filter at once through a double filter paper, and wash with boiling distilled water until a few cubic centimeters of the filtrate gives no reaction (red brown precipitate) when tested with a few drops of potassium ferrocyanide. *Never let the pulp on the filter dry while washing.*

Remove pulp to a beaker, and wash the filter paper free of the now red earth. To this mixture, add about 10 c.c. of concentrated nitric acid, and place on water bath until all the copper is dissolved.

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Filter on single filter paper, and wash free of copper (using ferrocyanide test) with hot distilled water. During the washing, add a few drops of ammonia to a little water, and pour over the pulp. Absence of blue color indicates that all the copper is washed out. Wash again with a little water. Now add a few drops of concentrated nitric acid to a little water, and pour over the pulp; filter, to dissolve any copper that possibly might still be present in the filter paper, and wash free of copper. Evaporate the washings and filtrate to dryness. Add a few cubic centimeters of concentrated nitric and sulphuric acids, and heat on a sand bath, to destroy any organic matter. Dissolve in nitric acid, filter into electrolytic beakers, and electrolyze with a current of 2 to 3 amperes under a pressure of 4 to 6 volts. Weigh the amount of copper deposited on the platinum cathode.

As an alternative method, the extract thus obtained may be concentrated to 1 to 2 c.c., diluted to 25 c.c., barely neutralized with ammonia, and again made acid with acetic acid. An excess of potassium iodide (10 c.c. of 30% solution) is then added, and the iodine set free is titrated with a standard thiosulphate solution, using starch as an indicator.

The copper figure, Cu. F., is then calculated by either of the formulas,

$$\text{Cu. F.} = \frac{\text{weight of copper} \times 100}{\text{weight of bone-dry pulp}} = \frac{\text{Cu} \times 100}{\text{wt. b.-d. pulp}}$$

$$\text{Cu. F.} = \frac{\text{Cu} \times 100}{\text{wt. of pulp}} \times \frac{100}{100 - \text{moisture \%}}$$

71. Discussion.—An oxycellulose, or copper value, of the pulp can be obtained throughout all stages of bleaching. Tests taken throughout the bleaching action on a certain lot of sulphite stock gave the curve shown in Fig. 22. Note that there is first a quick rise, then a slow drop, and finally a rise, rapid at first and gradually flattening out. The curve shows that the copper value obtained from unbleached pulp is entirely different from that obtained from bleached pulp. That is, the coloring matter and lignin in unbleached pulp, which reduce Fehling's solution, are gradually destroyed, while, at the same time, true oxycellulose is being formed. The formation of oxycellulose is most rapid when the concentration of bleach is highest. It is not probable that all the reducing compounds present in unbleached pulp are inactive at the finish.

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RESISTANT CELLULOSE TEST

72. Object of Test.—This test measures the amount of true cellulose present in a sample by removing the impurities, such as the carbohydrates and, also, the oxycellulose. The test depends on the fact that when wood pulp is exposed to the action of a strong caustic soda solution, a part of the carbohydrates (hemicellulose), lignin, etc., are dissolved. The quantity that goes into solution depends on the degree of concentration of the caustic soda solution. The per cent of cellulose that remains intact

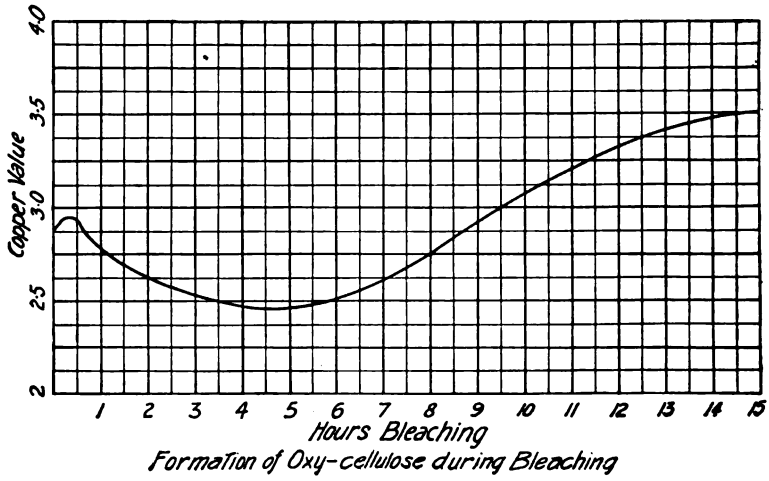

FIG. 22.

after exposure to a 17.5% solution of caustic soda is arbitrarily called the **resistant-cellulose content** of the pulp. The resistant cellulose content is, evidently, not a distinct measure of the bleaching action, which, nevertheless, has considerable effect on it.

73. Details of Test.—The sample of pulp is dried at 105°C. to constant weight, and 10 grams of the pulp is transferred to a 300 c.c. mortar. The pulp is covered with 50 c.c. of 17.5% caustic soda solution, and is rubbed with a pestle until the pulp has entirely lost its form.

After the pulp has been exposed at room temperature to the action of the caustic for half an hour, it is transferred to a Büchner funnel and thoroughly drained, the draining action being aided by a vacuum. A piece of high-grade linen is used as a

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filter cloth. The pulp is successively washed with increasing amounts of warm distilled water, until the jelly-like cake has been completely reduced; it is again washed with 100 c.c. of 10% acetic acid, and again with water, until the filtrate is neutral. The pulp is then put in a drying oven, and is dried to constant weight. The filter cloth is weighed along with the pulp, then carefully cleaned, and weighed separately. The weight of the pulp residue multiplied by 10 is the per cent of resistant cellulose.

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REFINING AND TESTING OF PULP

EXAMINATION QUESTIONS

(1) State the reasons why wood pulp contains particles too large for paper manufacture.

(2) What is meant by sliver? white shiner? knot? shive?

(3) Explain the principle of the ball mill refiner.

(4) What features are common to the kollergang and the stone-roll beater, and in what respects is the kollergang like the refiner shown in Fig. 7?

(5) On what principle does the Jordan type of refiner operate?

(6) What information should be used as a basis for the selection of a refiner?

(7) Name some of the tests made on wood pulp.

(8) In what forms is pulp shipped?

(9) What is meant by shipping weight, and how is this determined?

(10) How is a sample of pulp taken by the auger method: (*a*) from bales? (*b*) from rolls?

(11) Why is pressed pulp usually wet at the edges?

(12) For what purpose is pulp tested for moisture?

(13) If a paper mill buy a carload of pulp that weighed 48,320 lb. at the pulp mill and is charged for 26,576 lb., what was the per cent. of air-dry fiber in the sample tested? Ans. 55%.

(14) Referring to the last question, suppose the paper mill disputes the bill; if the referee finds that the weight of the pulp as delivered was 48,100 lb. and that the bone-dry weight is 20,400 lb., which wins, the pulp mill or the paper mill?

(15) What is meant by the freeness of pulp?

(16) How does a freeness test help the paper maker?

(17) How does temperature affect the freeness and sedimentation tests?

(18) Explain one method of testing the color of pulp.

(19) What substances in pulp reduce the copper in Fehling's solution?

(20) What is the significance of the copper number (copper figure) as applied to bleached chemical pulp?

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SECTION 9
BLEACHING OF PULP

By H. H. HANSON, S.B.

MANUFACTURE OF BLEACHING AGENTS

INTRODUCTION

1. Definition of Bleaching.—The **bleaching** of paper stocks may be defined as the destruction by oxidizing chemical action of organic substances that are in combination with or that accompany the cellulose itself. These substances, or **impurities,** as they are called, may consist of such wood substances as lignin and coloring matters that were not completely removed from the cellulose during the cooking of chemical pulp, organic dyes in rag stock, and dirt and other foreign matter found in old paper stocks. Bleach acts on these impurities to form new compounds that are soluble in water, and which may then be washed from the stock. The compounds thus created are usually colorless.

The bleaching material most commonly used is calcium hypochlorite or some related substance. Sulphur dioxide, sometimes called a bleaching agent, has an action somewhat different, as will be pointed out hereafter, though it accomplishes the same purpose to a slight extent.

2. Composition of Bleach Liquor.—As ordinarily used, the term **bleach liquor** means a solution in water of calcium hypochlorite $Ca(OCl)_2$. It is obtained either by the direct action of chlorine gas Cl_2 on milk of lime, a solution of calcium hydrate $Ca(OH)_2$, in accordance with the equation

$$2Ca(OH)_2 + 2Cl_2 = Ca(OCl)_2 + CaCl_2 + 2H_2O,$$

or by the solution of **bleaching powder,** which is a chemical compound containing lime and chlorine and having the molecular

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formula CaClOCl, which is frequently written $CaOCl_2$. Note the difference between the molecular formulas for calcium hypochlorite and bleaching powder; the former contains two atoms of oxygen and the latter only one. When bleaching powder is dissolved in water, the result is expressed by the equation

$$2CaOCl_2 + H_2O = Ca(OCl)_2 + CaCl_2 + H_2O.$$

Bleaching powder is manufactured by the direct action of chlorine on lime, as will be described later.

3. Action of Bleach on Wood Pulp.—Ordinarily, wood is thought to consist largely of a compound of lignin and cellulose, called *ligno-cellulose*. The composition of the cellulose molecule may be expressed by $(C_6H_{10}O_5)_n$, but the composition of lignin is not known; it is probably a mixture of several different substances.

It is certain, however, that the lignins contain particular groups of atoms that are easily acted on by chemicals, and that such chemical action often renders the lignin soluble, as in the cooking of sulphite pulp, for example. The action of bleach is quite similar; it practically finishes the preparation of cellulose from wood in reacting with and in destroying the last traces of lignin that were not removed by the cooking. Bleach, however, has a further action, for it decolorizes the compounds with which it reacts; it is therefore very beneficial in removing dyes, dirt, etc., which are very often found in paper stocks.

4. Oxycellulose.—The action of bleach may be very drastic; so much so, in fact, that if conditions are not just right, it will react with and destroy a considerable part of the cellulose itself. The substance formed when bleach reacts with cellulose is usually called **oxycellulose,** which is probably a decomposition product of cellulose. It is of very weak physical structure and is easily acted on by chemicals, such as caustic soda, which results in the formation of non-fibrous, or even of soluble, products. Its presence may be detected by caustic soda or by Fehling's solution, which it reduces.

It is practically impossible to bleach pulp on a large scale without forming some oxycellulose. However, its formation may be prevented to a considerable extent by careful control of the bleaching action. The factors of importance in this reaction are the quantity of bleach and the temperature of the reaction.

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A method of testing pulp, which gives an indication of the formation of oxycellulose (determination of the copper number) is explained in the Section on *Testing of Pulp*. It is there shown that the amount of oxycellulose increases as the bleaching progresses.

5. Effects of Bleach on Pulp.—Bleach acts first on the lignin and coloring matters and then on the cellulose. The *quantity* of bleach is thus not very important, provided there is enough lignin to react with it. But if there is much bleach left after the lignin and other easily oxidizable substances are destroyed, its action on the cellulose may be severe. The rate of reaction between cellulose and bleach increases rapidly with the temperature; hence, the higher the temperature the more oxycellulose formed, provided there is an excess of bleach. A temperature of 115°F. or over is very detrimental in a sulphite mill, while in a soda-pulp mill, 115°F. gives good results, the critical point in the latter being about 130°F. Temperatures higher than this result in loss of fiber by oxycellulose formation, and the color is not so good.

6. Necessity for Excess of Bleach.—It is impossible to get white pulp without a slight excess of bleach; and it is also a fact that at higher temperatures, the color obtained is a brighter and a more attractive white than at lower temperatures. It is a case of being between two fires, as it were: the oxycellulose formation must be kept down by using a minimum of bleach, but enough bleach must be used at a high enough temperature to get a bright pulp. Only by careful control can the best results be obtained.

It is often helpful to make laboratory tests of the color of pulps and to determine thereby the amount of bleach required to produce a desired result; this should be done for pulps of various colors and which have been cooked for various lengths of time. A test of the color of any blow (cook) then shows at once the approximate amount of bleach required. If, in the course of, say, half the usual time of cooking, the color at that stage is not up to standard, a little more bleach, the amount to be determined by experiment, is added. This method conserves bleach and renders the formation of oxycellulose less likely.

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MANUFACTURE OF BLEACH

7. Bleaching Powder.—Bleaching powder, frequently called **bleach,** is a white, ill-smelling, powdery substance that resembles slaked lime in appearance, but is somewhat more lumpy. It is purchased on the market in large iron drums or wooden casks, which contain about 800 lb. each, and may also be obtained from importers in small drums that contain about 400 to 500 lb. each; it must be stored in a dry place. Masks should be worn by operatives when taking the powder from the containers.

8. Available Chlorine.—Bleaching powder is purchased, usually, upon the amount of oxidizing power it possesses, which is based upon the *available chlorine.* Bleaching powder is sold on the basis of 35% available chlorine, which is a good average value of the strength, and the bleach may be figured on this basis. As a matter of fact, the bleaching powder of commerce may contain anything from 30% to 41% available chlorine, according to the length of the time and the conditions under which it has remained in storage. By **available chlorine** is meant that portion which acts in bleaching; that which is present as chloride or chlorate is not available. See *Elements of Chemistry,* Vol. II, under the heading, *Principles of Bleaching.*

9. How Bleaching Powder is Made.—Bleaching powder is usually made by passing chlorine gas over slaked lime, calcium hydrate. The reaction that takes place may be expressed by the following equation:

$$Ca(OH)_2 + Cl_2 = CaOCl_2 + H_2O.$$

This operation is accomplished in large rooms; the slaked lime is spread on the floor, the chlorine gas is admitted above it, and the lime, which is occasionally stirred, absorbs the gas. The bleach that results is packed in drums, when the proper strength in chlorine has been attained. In practice, this strength varies, as stated above, but it usually ranges from 34% to 41%. Bleaching powder that contains less than 34% available chlorine is generally "limey," which means that it is dusty and powdery, and it is slow to settle when dissolved; that which contains as much as 40% smells very strongly of chlorine gas, forms bubbles of gas easily in solution, and will not settle well. The best bleaching powder is that containing between 35% and 38% of available chlorine; this settles nicely in tanks and does not form an excessive amount of lime sludge.

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Bleaching powder in solution is considered to undergo a chemical rearrangement, whereby true calcium hypochlorite is formed, together with calcium chloride, in accordance with the equation

$$2CaOCl_2 = Ca(OCl)_2 + CaCl_2.$$

10. Chemical Reactions Produced by Bleaching Powder.—In the presence of substances that can be oxidized, such as many coloring matters, calcium hypochlorite gives up its oxygen, which, when set free, is *atomic*, i.e., nascent; thus, $Ca(OCl)_2 = CaCl_2 + 2O$. Note that the free oxygen is here written 2O, which signifies two free atoms of oxygen and not the molecule O_2. If, however, the temperature is high, there may be a loss through the formation of molecular oxygen, 2O becoming O_2.

The presence of an acid may cause liberation of chlorine; thus,

$$Ca(OCl)_2 + 4HCl = CaCl_2 + 2H_2O + 2Cl_2,$$

and the loss of chlorine is greater as the temperature rises. On the other hand, a little acid is often helpful as a catalyzer, especially in bleaching rags; thus,

$$Ca(OCl)_2 + 2HCl = CaCl_2 + 2HClO.$$

The hypochlorous acid decomposes very readily; thus,

$$2HClO = 2HCl + 2O,$$

and the acid then repeats its work. To secure this effect, a very weak acid should be used, and it should be added very slowly. Acetic acid is good for the purpose, but hydrochloric and sulphuric acids are sometimes used to neutralize free lime from the bleaching powder. The final result of the two reactions, as given in detail above, is that $Ca(OCl)_2 = CaCl_2 + 2O$, the HCl being merely a catalyzer and unchanged. Thus the 2 atoms of Cl in a molecule of $Ca(OCl)_2$, or the 4 atoms in $2CaOCl_2$, are equivalent to 2O, and each atom of Cl in $CaOCl_2$ supplies an equivalent ($\frac{1}{2}O$) of oxygen. All the chlorine in pure bleaching powder is therefore available. The presence of free chlorine is especially to be avoided if the pulp from wood still contains lignin, since lignin forms a yellow product with chlorine. In bleaching wood pulp and jute, the mass must be kept alkaline.

11. Analysis of Bleaching Powder.—As stated before, the constituents of bleaching powder vary; even the same powder changes with age and the conditions under which it is kept.

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This is well illustrated by the following analyses (quoted by Sutermeister) of a powder, which were made 11 months apart:

	(1)	(2)
Available chlorine	37.00	33.80
Chlorine as chloride	0.35	2.44
Chlorine as chlorate	0.25	0.00
Lime, CaO	44.49	43.57
Magnesia, MgO	0.40	0.31
Silicious matter	0.40	0.50
Carbon dioxide, CO_2	0.18	0.80
Alumina, iron peroxide, manganese oxide	0.48	0.40
Water and loss	16.45	18.18
	100.00	100.00

It is essential that bleaching powder be kept cool and that it be kept away from products of combustion.

QUESTIONS

(1) (*a*) What is the purpose of bleaching paper-making fibers? (*b*) What are the principal substances used?

(2) Why is the formation of oxycellulose to be avoided?

(3) (*a*) How is bleaching powder made? (*b*) What precaution must be taken in handling it?

(4) In what respects does electrolytic bleach differ from a solution of bleaching powder?

12. Electrolytic Bleach.—The term **electrolytic bleach** usually signifies a bleach solution that is made by bringing chlorine from electrolytic cells into contact with milk of lime, which is hydrated lime held in suspension in water. The reaction that occurs is similar to that described above. The term is in reality a misnomer, because it is the chlorine that is made electrolytically, and this is dissolved in milk of lime; the solution is essentially the same as that made by dissolving the bleaching powder.

Mills making and using electrolytic bleach claim that it is much more efficient than solutions of bleaching powder. One mill found that 20% more bleaching powder was required than when the equivalent amount of electrolytic bleach solution made from chlorine direct from cells was used. The difference is attributed in part to inefficiency of bleaching powder solutions, and in part to the presence of free hypochlorous acid (see Art. **10**) formed by the solution of some chlorine in water.

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There is also a process in which a solution of sodium hypochlorite may be made directly in cells and used in a manner that is similar to that in which bleaching powder is used, but this will not here be considered.

13. Manufacture of Chlorine by Electrolytic Cells.—Chlorine, a greenish-yellow, suffocating gas, is a chemical element and is a constituent of ordinary salt, sodium chloride NaCl. The two elements, sodium and chlorine, which form salt, may be separated from each other by passing a current of electricity through a solution of salt. When a chemical compound like salt is in water solution, the elements that make up the compound are largely separated into two parts, or *ions*, as sodium (Na^+) and chlorine (Cl^-), respectively. These ions bear a charge of electricity, sodium carrying a positive charge and chlorine a negative charge; the two charges attract each other, and thus prevent the two ions from separating and showing their peculiar and distinctive qualities. If, now, a current of electricity be passed through the solution, by means of two electrodes, or poles, immersed in it, the negatively charged chlorine will migrate toward the anode (which is the positive plate) and the positively charged sodium ion goes to the cathode (the negative plate). At these plates, the ions give up their electric charges, and become uncharged atoms, this discharge being the means by which the current passes. The chlorine element passes off as a gas at the anode, while the sodium element at the cathode immediately reacts with the water present in the same manner as metallic sodium (see *Elements of Chemistry*, Vol. II), releasing hydrogen from the water (which passes off as a gas) and forming sodium hydrate NaOH, which remains in solution. The process may be thus illustrated:

NaCl (in water) = Na^+ (positive ion) + Cl^- (negative ion);

the electric current discharges the ions, which then become plain atoms; finally, these atoms become molecules; thus,

$$Na + H_2O = H + NaOH$$
$$H + H = H_2 \text{ (molecule of gas)}$$
$$Cl + Cl = Cl_2 \text{ (molecule of gas)}$$

As a matter of fact, the process takes a sort of short cut in the diaphragm cell (about to be described); there are both hydrogen and hydroxyl ions already in the water, in small amounts Hydrogen ions discharge more easily than sodium ions; therefore

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the former have their charges neutralized and escape as molecules, while the latter take their places as partners of the deserted hydrogen ions, forming caustic soda. More and more molecules of water continue to break up to supply the hydrogen ions and the hydroxyl ions required by the new sodium ions, thus,

$$H_2O = H^+ + OH^-$$

14. The Chlorine Diaphragm Cell.—A typical chlorine diaphragm cell is shown in section in Fig. 1. Brine is fed continuously through the pipe *J* into the compartment *E*, called the *anode chamber*, which is separated from the two chambers *B*, the cathode chamber, by the asbestos paper diaphragm *D* and perforated iron plates *C*. In the anode chamber are the graphite plates *A*, called the *anodes*, or positive plates; the *cathode*, or negative plate, is the perforated iron plate *C*. The brine filters through the diaphragms, coming into contact with the cathodes. The current flows from one electrode to the other (from the anode to the cathode) liberating, as described above, chlorine at the anode and hydrogen at the cathode, which passes out through the pipe *H*. The sodium left behind combines with the hydroxyl of the water to form caustic soda. The chlorine, which is liberated at the cathode, passes out through the pipe *G*, and the caustic soda NaOH is discharged through the pipes *F*. The caustic formation occurs after the solution passes through the diaphragm,

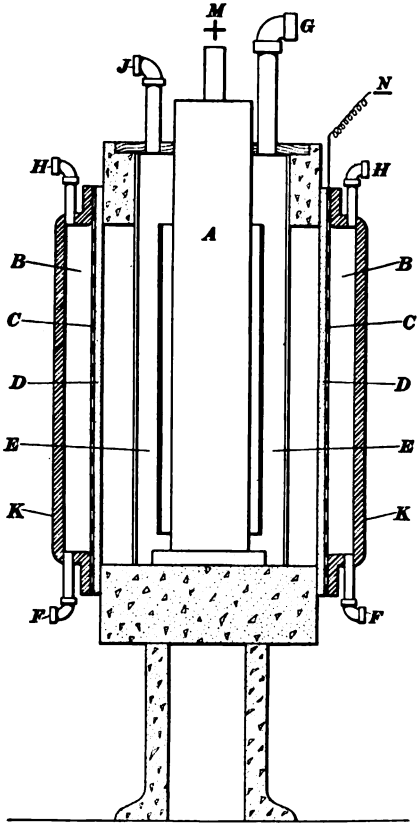

FIG. 1.

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and the diaphragm thus serves to keep the caustic soda and the chlorine apart. If they were allowed to mix, an immediate reaction would take place, and sodium hypochlorite, which is not desired in this cell, would be formed. The cathode chamber is formed by the perforated cathode on one side and the iron

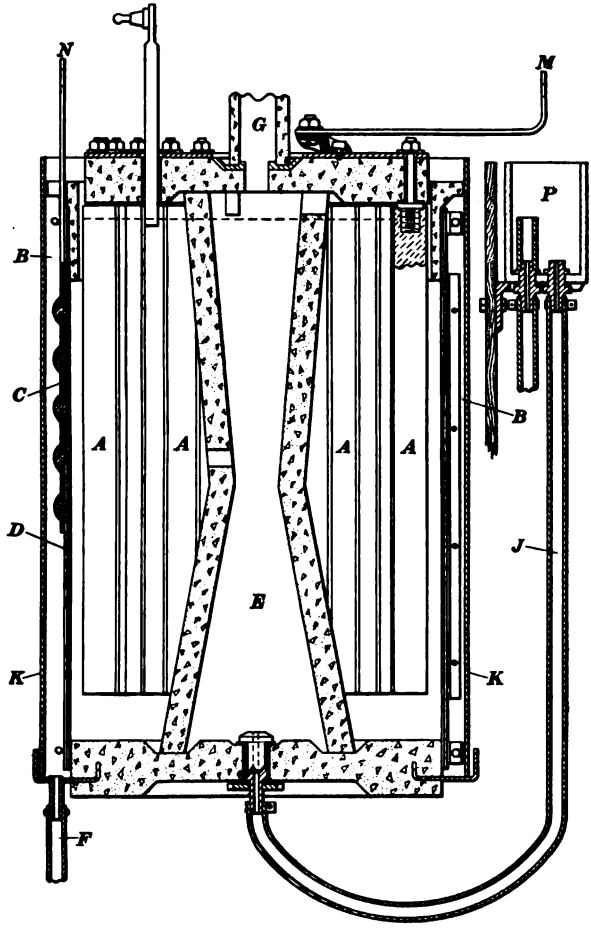

FIG. 2.

box K on the other, and the current flows through the latter to the cathode. The body of the cell is usually of concrete; it is set up on a support that is a non-conductor of electricity, to prevent loss of current into the ground. The current enters on bus (conductor) M and leaves at N. Some of the original

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salt passes off with the caustic soda, but is recovered by evaporating the solution until the salt crystallizes; the salt is thus separated from the caustic soda, which is much more soluble and remains in solution.

15. Other Cells.—There are several other types of diaphragm cells in use in America. The principle is the same in all, but they vary somewhat in construction. For example, the one shown in Fig. 2 is cylindrical, and has a central anode compartment *E* enclosed by a set of graphite anodes *A*. The diaphragm *D*, perforated cathode *C*, and cathode chamber *B* surround the graphite in turn. The reference letters indicate the same details as in Fig. 1. A constant flow of brine is maintained by controlling the level in feed box *P*.

In one make of cell, an oil is forced through the cathode chamber, to assist in carrying off the caustic liquor and to equalize the pressure of the anode liquor on the diaphragm.

16. Mercury Cells.—Another type of cell, one that does not have a diaphragm, is the **mercury cell.** Graphite is ordinarily used as the anode, and the current flows from it downwards, through the brine solution, to a layer of mercury, which rests on the bottom of the cell and which acts as the cathode. Sodium ions give up their electric charges more easily at a mercury cathode than the hydrogen ions do; hence, hydrogen is not formed when the cell is operating properly. As the sodium ions discharge, they form metallic sodium, which dissolves in the mercury and forms sodium amalgam (see *Elements of Chemistry*, Vol. II, under *Amalgams*). When the concentration of sodium in the mercury has reached the desired point, the mercury is replaced by fresh material. The removal of mercury may be continuous or it may be in the form of charges. Chlorine passes off at the anode in the usual way. The sodium is removed from the mercury by the action of water; the sodium amalgam is an alloy, not a chemical compound, and when it is brought into contact with water, the sodium immediately reacts with the water in the same manner as though it were free, caustic soda and hydrogen being formed and the mercury left free.

Mercury cells differ principally in the method whereby the mercury cathode is replenished.

17. Description of Mercury Cell.—A type of mercury cell that is extensively used is shown in Fig. 3. The cell consists of an

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enclosed box, which is supported by a hinge 14 at one end and by an eccentric roller 15 at the other end, thus providing for a tilting (up-and-down) movement of about ½ inch. The box is divided into three compartments, of which *A* and *B* at either end are anode chambers, while the larger middle compartment *C* is the cathode chamber. The anodes 1 and 4 are carbon plates, which are suspended from the top of the box. The principal cathode is a layer of mercury 2, which rests on the bottom of the box. The partitions *D* and *E* do not extend completely to the bottom of the box, but dip into grooves that are filled with the mercury, as shown, which thus entirely seals the middle compartment from the other two. A secondary iron cathode 5 is suspended in the chamber *C*. With the cell in the position shown, the mercury is principally in chambers *A* and *C*. Brine is fed into *A* through pipe 8, and is decomposed by the current passing from anode 1 to the mercury below. The chlorine passes out through pipe 10, and the sodium is discharged at the mercury cathode, where it amalgamates with the mercury before it has an opportunity to react with the water. When a sufficient quantity

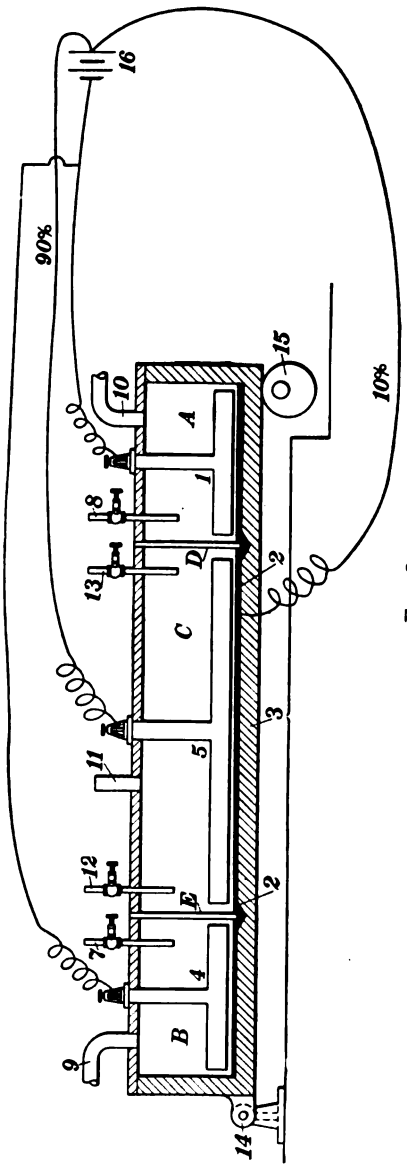

FIG. 3.

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of amalgam has been produced, the eccentric 15 revolves (about once per minute) and tilts the box, so that the amalgam that has been formed flows under partition *D* and into the cathode chamber *C*. Here it is decomposed by water, which is fed in through pipe 12. The sodium unites with the water to form hydrogen (which escapes at 11) and sodium hydrate (which is discharged at 13). The reactions that have been going on in chamber *A* are now repeated in chamber *B*, into which the mercury from the decomposed amalgam in *C* has passed by reason of the tilting of the box. The chlorine escapes at 9 and the brine enters at 7. The reaction in *A* now ceases until the next periodical tilting of the box, which will send the amalgam formed in *B* into chamber *C* and the mercury (which has been freed from the sodium in *C*) into *A* again. As will be noted, the electric circuit is divided; this insures that the iron cathode 5 and the mercury cathode 2 shall be charged alike, which prevents any formation of chlorine in chamber *C*, since this would contaminate the hydrogen, cause a waste of chlorine, and might cause an explosion. Dividing the current also prevents loss of mercury. As will be seen, the discharge of sodium from the amalgam in chamber *C* is a continuous process. The source of direct current is represented at 16, and the drawing indicates that 10% of the current goes to the mercury cathode and 90% to the iron cathode.

In another cell of the mercury type, a pump is used to transfer the mercury from the cathode chamber to the anode chamber. As before stated, the method of handling the mercury constitutes the principal difference in cells of this type.

18. Strength of Brine and Efficiency of Cells.—The brine used in electrolytic cells is a saturated solution of a good quality of salt in water; this requires about 250 grams of salt per liter of water or about 16 pounds per cubic foot.

The efficiency of a cell depends on the voltage and current taken for a given production of chlorine and caustic soda. The voltage depends on: (*a*) type of anode; (*b*) current density; (*c*) temperature; (*d*) distance between the electrodes; (*e*) concentration of brine.

The last two of these may be left out of the discussion, because the distance between the electrodes is always made as small as possible by the manufacturer, and a saturated brine is always used. The two common anodes used in this country are graphite and carbon. Graphite is much more efficient, but is more expen-

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sive. As the temperature rises, the resistance to electric current decreases until a point is reached where the high temperature makes the action of the cell chemicals on the parts of the cell too harsh. A satisfactory temperature at which to operate is 135°F. Increase in current density means increase in voltage. About 65 amperes per square foot of cathode surface is common practice. The theoretical voltage for a chlorine-caustic cell is 2.3 volts, but in actual practice it runs from 3.5–5.0 volts; 4 volts is very satisfactory in operation.

The current efficiency is the ratio of the actual production of chlorine divided by the theoretical production for a given current. Losses in current efficiency are obtained chiefly by poor removal of the caustic at the cathode. If the caustic is not readily removed as it is formed, it will work back into the cell proper and react with chlorine. Hence, to get a high current efficiency it, is necessary to have as rapid a flow of brine through the cell as possible without so decreasing the amount of salt converted as to make evaporation of caustic and recovery of salt uneconomical. The cell should operate at 90% current efficiency. In ordinary practice, about 45% of the salt is actually converted to chlorine and caustic soda. The rest is sent through with the caustic and recovered.

In figuring the efficiency of a cell, the product of amperes and volts should be considered, because power is what is bought. The theoretical production of chlorine per kilowatt-hour is .58 kilograms. In actual operation (90% efficiency and 4 volts), about .3 of a kilogram per kilowatt-hour should be obtained. This is equivalent to 1 kilogram per 3.33 kilowatt-hours or 4.5 horsepower-hours.

19. Absorption of Chlorine.—The chlorine from the cells is passed into some form of apparatus in which the chlorine comes into intimate contact with milk of lime. The reaction that takes place is shown by the following equations:

$$Ca(OH)_2 + Cl_2 = CaOCl_2 + H_2O,$$

and

$$2CaOCl_2 = CaCl_2 + Ca(OCl)_2$$

or

$$2Ca(OH)_2 + 2Cl_2 = CaCl_2 + Ca(OCl)_2 + H_2O.$$

This reaction may take place in a *tower*, in which the chlorine gas passes upward and a spray of lime water is rained through the gas; or it may take place in what is known as a *scrubber*, in which the milk of lime is splashed through the gas current. Another

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plan is to pump the chlorine gas under a slight pressure into a tank of milk of lime, which is thoroughly stirred. In either case, the chlorine is brought into contact with a finely divided spray of milk of lime, in which there is always more lime than is required to absorb the chlorine. The solution so formed is then allowed to settle (Art. **27**), after which, the supernatant liquid is decanted and adjusted to the proper strength for use in the bleaching department. Some mills use the bleach liquor as weak as 15 grams of available chlorine per liter, while others prefer it as strong as 50 grams per liter. The sludge should be washed by stirring up with water, and again settled; this water will contain some bleach, and it is used to make milk of lime.

20. Excess of Lime is Necessary.—It is always necessary to have an excess of lime present, and it is also necessary that the temperature be kept low. If the excess of lime is not properly maintained, the chlorine forms calcium chlorate instead of the hypochlorite, as indicated by the following equations;

$$6Ca(OH)_2 + 6Cl_2 = Ca(ClO_3)_2 + 5CaCl_2 + 6H_2O,$$

or

$$3Ca(OCl)_2 = Ca(ClO_3)_2 + 2CaCl_2.$$

When this reaction is taking place, a pinkish color appears in the bleach solution. The chlorate not only causes a loss of bleaching powder but it is also liable to attack the cellulose.

It is highly important that all bleach solutions should be settled a second time, and filtration is sometimes resorted to, in order to keep any of the hydrated lime from getting into contact with fibers. Many mills allow the decanted liquor from the settling tanks to re-settle, and this generally keeps any of the free lime from reaching the bleaching department. Satisfactory results have been obtained by filtering the bleach solution through a sheet of pulp, laid over wire cloth (old Fourdrinier wire will do) in a plate and frame filter press. A new material, which promises good results, is filtros. The ordinary depth of the settling tank, about 5 feet, provides sufficient head to force the solution through the filter.

21. Hypochlorites from Liquid Chlorine.—Some mills are making their bleach solutions from liquid chlorine, marketed in cylinders, drums, and tank cars. The principle of absorption in lime water is the same as for chlorine made at the mill. The liquid chlorine is first evaporated by placing the container in a suitable hot-water bath. A typical installation is shown dia-

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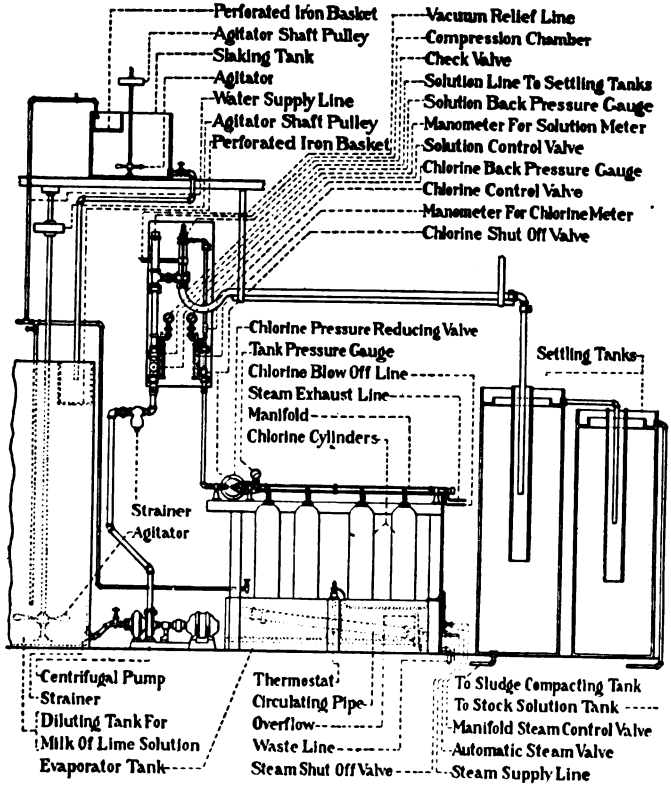
grammatically in Fig. 4. When sodium hypochlorite solution is made from chlorine and caustic soda or soda ash, no settling tanks are required.



Typical installation for making calcium hypochlorite solution from chlorine and milk of lime.

FIG. 4.

22. Making Electrolytic Bleach at Mill.—Among the advantages of making electrolytic bleach at the mill are: ease with which it is made; elimination of all the disagreeable features attending the handling of dry bleaching powder; and the fact that it can be made as needed. In most locations, it is cheaper to manufacture the bleach as previously described than to use the dry bleach, because there are not so many losses in the manufacture of bleach in solution as there are in the making of bleach as a dry powder.

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23. Hypochlorite Cells.—Another type of cell, the hypochlorite cell, is extensively used in bleaching cloth and, to some extent, in bleaching paper stocks. In this cell, the products of the reaction, chlorine and caustic soda, are allowed to combine immediately after formation in the cell, and a solution of sodium hypochlorite NaOCl is produced. In this cell, there is no diaphragm to separate the anode and cathode. The reaction is usually written

$$2\ NaOH + Cl_2 = NaOCl + NaCl^1$$

It will be noticed that half of the salt is regenerated, and sodium hypochlorite bleach made in this way has the advantage that no insoluble calcium salts can be formed. The disadvantages are high power (energy) consumption and high salt consumption. Secondary reactions that form chlorates take place very rapidly when the hypochlorite content in the cell liquor is still low, causing a waste of power (energy) and permitting only a fraction of the salt to be economically converted to the hypochlorites.

BLEACHING THE STOCK

OPERATIONS PREPARATORY TO BLEACHING

24. Effect of Cook on Bleaching.—The pressure, temperature, time consumed in cooking, and the chemical conditions in the digester, have an important bearing on the bleaching of chemical pulp. In general, the more drastic the action of the chemicals, whether because of high concentration, higher temperature and pressure, or longer cooking, the easier it is to bleach the product. Under cooking means high bleach consumption and poor color; it also means that shives will be present in the stock, which can be removed only by very careful screening or by a large excess of bleach. In cooking pulp, the presence of an unduly large amount of calcium makes pulp difficult to bleach.

25. Washing Stock.—When a digester of pulp is blown, the substances dissolved from the wood, liquor and resinous matter,

[1] Recent investigations appear to show that the reaction is expressed by the following equation,

$$2NaOH + Cl_2 = Na_2OCl_2 + H_2O,$$

the molecular formula Na_2OCl_2 agreeing in form with that for calcium chloro-hypochlorite $CaOCl_2$ and suggesting a similar decomposition.

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accompany the stock to the blow pit or wash tanks; all these substances react freely with the bleach. Moreover, in the case of resinous matter, the product of the reactions may be a gum that is absorbed in the fiber. Therefore, it is very important that the stock be thoroughly washed before bleaching. Hot water should be used for this, particularly at the start, since the impurities, if cold, adhere very strongly to the fibers. Stock that has been thoroughly washed will consume a minimum of bleach. Details of cooking and washing are given in the Sections on Manufacture of Pulp.

26. Preparation of Bleaching Solution.—If electrolytic bleach be used, it is already prepared when the excess lime is settled out as described in Arts. **19** and **20.** If the solution is to be made from bleaching powder, a separate operation at the bleach house is necessary.

27. Bleaching powder is received in drums, which should be kept air tight, or deterioration of the product will result. The tank in which the bleach solution is made should be approximately half filled with water; the powder is dumped in and sufficient water is added to fill the tank to the top. Thorough agitation by means of a stirring device for about 45 minutes is now carried on. The tank is then allowed to settle, the time allowed for this varying with the character of the bleaching powder, and the clear liquor is drawn off. The tank is again filled with water, agitated for about 30 minutes, settled, and decanted. A second wash is now run in, and the last operation is repeated. The amount of water that is generally used is about 1.4 gallons per pound of bleach in the first tank full; this gives a first liquor of 5½°–7°Bé. The first wash should be about 2°Be.; and when this is mixed with the first liquor, a mixture of about 4.2°Be. is obtained. The second wash, which should be about 0.1° to 0.5°Be., should be drawn off to a storage tank and used for making up the next batch. The sludge that remains should be dumped out of the mixing tank, and the tank should be washed clean.

For the best operation, the loss of bleach should not be over 2%. Careless washing of the sludge or careless mixing may run this loss up to 10% or even 20%.

28. One of the most important features of this operation is the temperature of the water, since water that is either too hot or too cold will cause poor settling; if too hot, there may also be a loss

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of chlorine. The most efficient temperature range is between 70° and 75°F. During the cold winter months, it is therefore necessary to heat the water before it is used in dissolving bleach; the mixing tank should be provided with a steam line, so that the proper temperature can be maintained.

29. Effect of Heat on Bleach Solutions.—Bleach solutions should never be brought into contact with live steam or with hot steam pipes, because they rapidly decompose into chlorides under these conditions, giving off oxygen in an alkaline solution and forming chlorates and chlorides in an acid solution. When it is necessary to make up a bleach solution in cold water, it should never be agitated by the introduction of live steam into the tank. Where the steam strikes the liquid, all the bleach in contact with the steam will be decomposed. A solution so made will be high in chlorides, possibly in chlorates, and it will be much weaker in bleach than it should be. If the water is too cold to make a satisfactory solution, it should be heated in a separate tank before being brought into contact with the bleaching powder. Water having a temperature of between 70° and 80°F. absorbs the bleach very rapidly; but water above 100°F. should not be used, if it can be avoided.

OPERATION OF BLEACHING

COMMON METHODS

30. Old Bleaching Systems.—The bleaching operation is very simple. In the older systems, the bleach and stock are mixed in a large tank, provided with means of agitation (usually a paddle or compressed air), and steam is admitted, to heat the mass to the required temperature. After a number of hours, depending on the stock and the results required, the mass is dumped to the drainer and washed. In more recent installations, the stock passes continuously through a series of tanks; the mixing of the stock and bleach takes place in the first tank, and the bleached stock is discharged from the last tank. In both these systems, the tanks used are made of brick or wood, and the system is usually closed. The chief drawbacks of these systems are:

(*a*) Inefficient mixing of bleach and stock.

(*b*) Low consistency of stock is necessary, in order that the

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agitation and mixing be sufficient; this means a weak bleach solution or too much bleach.

(*c*) Difficulty in temperature control.

(*d*) The chances of contamination by dirt from the walls of the tank are great; and if air be used as an agitator, compressor oil and grease may be admitted with it.

31. Improved Systems.—There is a late type of continuous tank system that eliminates the above objections to the older systems. This newer type, however, consumes unduly large quantities of power (energy), which renders it unfit for the mill of low productive capacity, unless very cheap power is obtainable. The general scheme of the system is as follows:

The pulp stock, at a consistency of around 4% air-dry fiber, is pumped to a series of stock thickeners of the decker type; (See Section on *Treatment of Pulp.*) The couch rolls used consist of a heavy metal core, wound with felt, and which weigh up to about 4000 pounds each. The combination of heavy weight and soft, yielding surface produces a sheet of pulp over the doctor of very high consistency, the exact figure depending on three main factors: (*a*) speed of stock thickeners; (*b*) weight of couch roll; (*c*) consistency of entering stock.

By this method, stock consistencies have been obtained of 10% to 25% air-dry fiber. In operation, the consistency is varied, according to what result is desired, by regulating the dams in the white-water outlet, which consequently regulates the level at which the stock is carried on the cylinder mold; the thinner the sheet the drier the fiber.

32. Mixing Bleach Liquor and Stock.—The intimate mixing of the bleach liquor with the stock is obtained as follows: A header pipe is placed just above the doctor of the stock thickener, parallel to the doctor, and this pipe is drilled with small holes that are spaced close together. The bleach liquor is thus shot, practically in the form of a spray, on the sheet of pulp as it passes beneath the spray pipe over the doctor. After leaving the doctor, the pulp falls into an open trough, in which runs a screw conveyor, which takes the pulp to the opening in the top of the first bleaching tank. The action of the screw conveyor results in breaking up the bleach-impregnated sheet of pulp into small particles and thoroughly mixing them together.

With such high consistencies, it is not possible to pump the

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stock by centrifugal pumps, as is usually done, from one tank to the other, so enclosed worm conveyors are used. It is the driving of these conveyors that causes the greater part of the increase in power consumption; considerable power is also required to drive the agitators. But the chief difficulty here, for any mill of small productive capacity, is the cost of agitator equipment that is necessary to withstand the excessive strain due to stirring the stiff mass of pulp. The chances for contamination by dirt from the walls of the tank are minimized by lining them with enamelled brick.

33. Use of Stock Thickeners for Washing Bleached Pulp.—After the stock leaves the last tank, fully bleached, instead of being dumped to a drainer for washing, it is thinned out and pumped to a series of stock thickeners, several types of which are described in the Section on *Treatment of Pulp*. A series of strong ½-inch jets of fresh water are sprayed on the stock as it passes over the doctor of the first thickener, thus thinning it out and diluting the residual bleach left in it. The stock falls into the vat of the second thickener, which contains an agitator that is similar in principle to the whipper on the felt of a wet machine. This agitator intimately mixes the fresh water with the residual bleach and the decomposition products that cling very persistently to the fibers; thus, on thickening up the stock again, more bleaching products are washed away in the white water.

A sufficient number of thickeners are used, so that when the pulp leaves the doctor of the last one, only very minute traces of decomposition products or excess bleach are discernible. This system is very efficient, due to the agitation that is necessary to secure intimate mixing of fresh water with the stock, which is not accomplished in the ordinary drainer tank.

34. A Widely-Used System.—A plan view of a widely used bleaching system is shown in Fig. 5. A_1 and A_2 are two short worm conveyors, operated on a single shaft in the same casing by the motor M; B is a central channel, and C_1 and C_2 are two side channels, through which the stock circulates. The tubs are sometimes made with only two channels. The whole system is lined with glazed tile, thus making cleaning a simple problem and preventing contamination of the pulp. D_1 and D_2 are steam pipes for temperature control. The conveyor draws material from the side channels C_1 and C_2, and throws it into the central

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channel *B*, giving positive and continuous circulation. The operation of the system is as follows:

Stock at 5% to 7% consistency is run into the conveyor case, accompanied by bleach. As soon as the opening between the conveyor case and the channel *B* is closed by the stock, steam is turned on, carefully at first, so it will not blow through and be wasted. The filling operation may last as long as 3 hours, depending on the size of the unit and the flow of stock. The circulation of the stock as a whole around the side channels and through the conveyor does not start until the filling is practically complete, because the stock is of high consistency. The temperature of the stock before circulation begins is low; hence, little or no bleaching occurs up to this point; this gives the stock a chance to absorb the bleach thoroughly, so the action can be uniform throughout the fibers when the bleaching takes place. As soon as the chamber is filled and circulation started, the temperature is raised from about 60°–75°F. to 95°–102°F., depending on the speed of bleaching desired and the condition of the stock. The steam is then shut off, and the temperature is allowed to fall slowly.

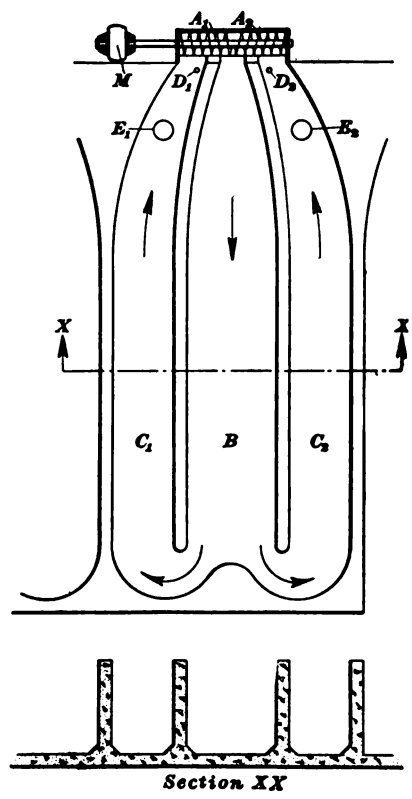

FIG. 5.

The heating should be complete after 4 to 5 hours, and the bleaching after 8 to 12 hours. After the bleaching is finished, the stock is dumped to drainers through pipes E_1 and E_2, and the bleach water is washed out. No excess bleach should remain. Excess bleach may be tested for by adding to a handful of stock a few drops of a solution of starch that contains a little sodium or

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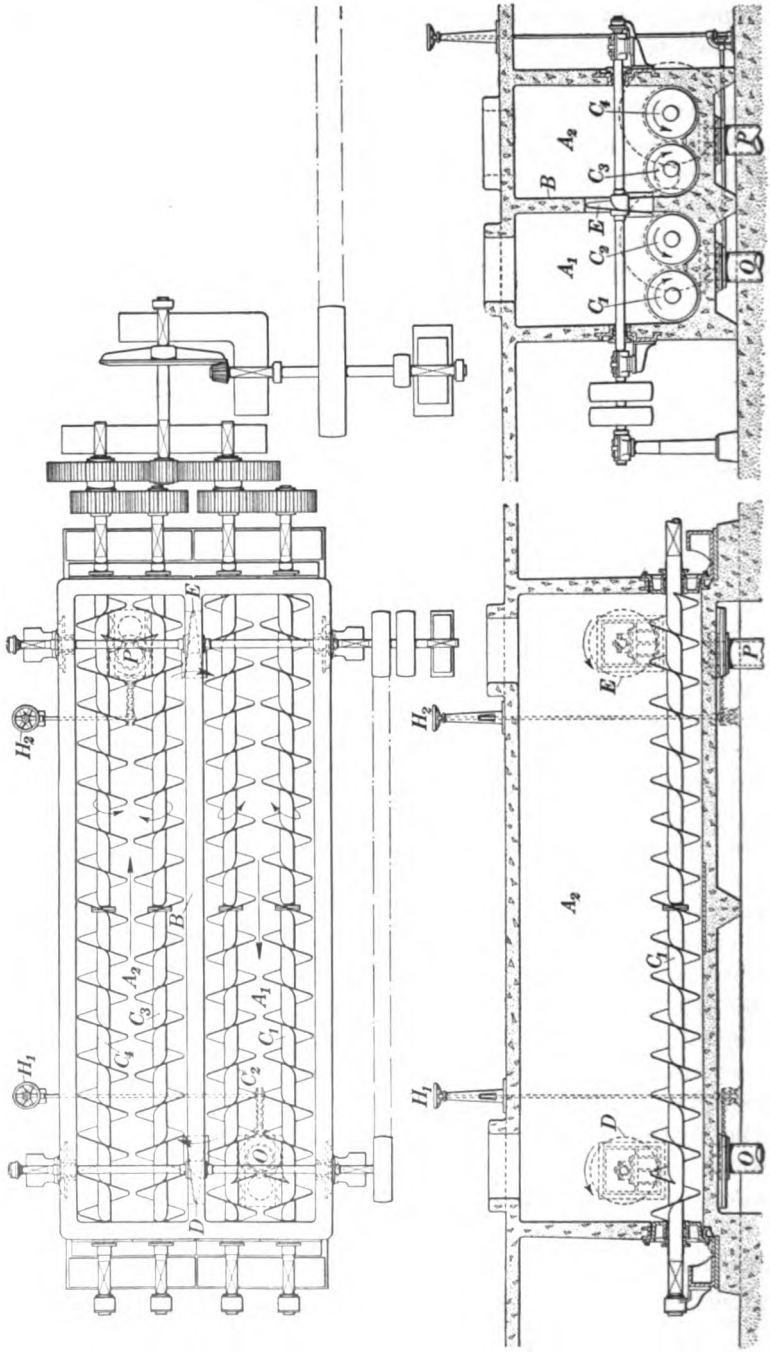

FIG. 6.

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potassium iodide; if a blue color appears, an excess of bleach is present. The conveyor runs at 350 r.p.m.; it requires 30 h.p. to operate it for a tub holding 10,000 pounds of air-dry pulp.

Except where very large digesters are used, it is advisable to have the bleachers of such capacity that the stock from each digester may be bleached separately; this allows proper variation of the bleaching process, to provide for differences in cooking.

35. New Type of Bleaching Tub.—In Fig. 6 is shown a recent design of bleaching tub. It consists of two vats, or channels, A_1 and A_2, separated by the partition B. In the bottom of each channel, is a pair of screw conveyors C_1 and C_2, C_3 and C_4, and the channel bottom (bottom on drawing) is shaped to form two semi-circular depressions, which correspond to the shape of the propellers. At each end, near the bottom of the dividing wall, are other (short) worms D and E. The worms rotate in the direction indicated by the arrows, causing the pulp to be pushed toward the left in channel A_1 and toward the right in channel A_2. The worms D and E act to pass the pulp from one compartment to the other. This method of circulating the pulp permits concentrations of 10% to 15%, which naturally gives a greater efficiency of operation. An important advantage is the saving of steam in bleaching at lower temperatures; at the same time, there is less loss of fiber and cleaner pulp. There are two outlet pipes O and P, which are operated by gears that are connected to hand wheels H_1 and H_2 on the operating floor. The whole tub is enclosed, with the exception of a manhole at either end; and, for highest grade pulp, it should be lined with tile.

36. Bleaching in Beaters.—The beater, when used as a bleaching tub, or **potcher,** as it is called in England, is essentially as shown in Fig. 7. The stock is fed into the tub A, which is elliptical in shape and is divided down the center by the mid feather B. Hung in one side of the tub is the roll C, which carries on its circumference a number of blades or paddles for circulating the stock. As the roll turns in the direction indicated, the stock is drawn past a bed plate D and lifted over the back fall E, which gives it sufficient momentum to carry the mass around the tub and then back under the roll. There is also a washing cylinder F, which consists of a series of dippers, covered with wire cloth for straining and removing the wash water. This machine is used principally in the bleaching of rag stock, but it is also used by

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paper mills that buy unbleached chemical pulp. The agitation by the roll *F*, which can be raised or lowered, serves to mix the bleach solution with the fiber and acts to unravel pieces of rag and break up chunks of pulp. The washing cylinder is frequently lowered previous to adding the bleach for concentrating the mixture, and after bleaching, may be used for washing out chemical residues. The stock is discharged through opening *H*.

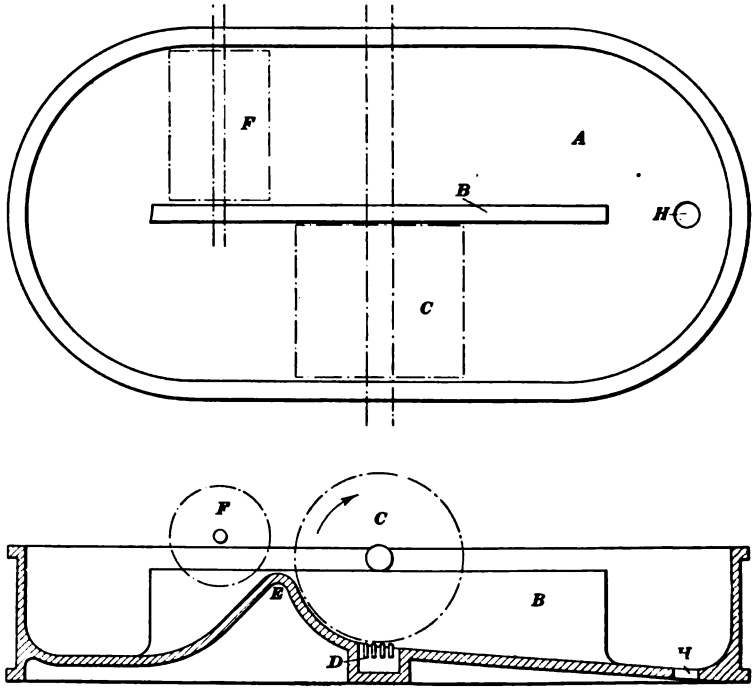

FIG. 7.

37. Control of Bleaching Operation.—The chief factors in bleaching are: (*a*) saturation of fibers at low temperature; (*b*) thorough mixing of stock and bleach; (*c*) agitation; (*d*) minimum bleach at maximum concentration; (*e*) control of maximum temperature. Each of these features will be considered in detail.

(*a*) Bleaching action is very slow at low temperatures. If the fibers are saturated with bleach by thorough mixing at low temperature before bleaching occurs, a more even result is obtained.

(*b*) Unless there is thorough mixing of stock and bleach, too

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low concentrations of bleach are obtained in some places and too high concentrations in others. Thus a mixture of under-bleached and over-bleached pulp results, which means a poor color, a weak stock, and loss of cellulose.

(*c*) Agitation is a continuation of the original mixing and is necessary for the same reasons.

(*d*) It has been previously stated (Art. **4**) that excess bleach will react with pulp and produce oxycellulose, which means weak pulp. On the other hand, too weak a bleach concentration will not act properly on the impurities; it should be in concentrated form for proper action. This means maximum pulp consistency. The exact quantity of bleach can be determined only by experimentation on a given grade of stock. The consistency should not be under 5%, and 6% is better.

(*e*) The higher the temperature the more violent the bleaching action. However, if the proper amount of bleach is added, so there is no excess to react with the pulp, the temperature may be raised fairly high without deleterious results. Since, in practice, there is usually not time to determine the proper amount, it is advisable to keep the temperature below 95°F., except on hardwood pulp, when a temperature of 115°F. may be required; this latter stock will not bleach under 100°F.

Common maximum temperatures of operation run from 90° to 120°F.; the higher the temperature the brighter the pulp, until about 130°F., when the color is affected adversely. But high temperatures are dangerous, because there is always a chance that excess bleach may be present. It is not definitely settled whether high temperatures cause excessive consumption of bleach, due to the formation of chlorates or the liberation of oxygen, or whether, unless carefully controlled, bleach is consumed in attacking cellulose. In either case, the final result is a *loss*, and it is important that the temperature should not be high when the bleach is added. A recording thermometer ought to be used, in order that the best control of the operation may be had.

38. Washing Bleached Pulp.—After bleaching, the stock must be carefully washed, because the coloring matter that has been oxidized tends to return to its former condition after all the bleach is gone. This is especially true when the temperature is allowed to remain high. Also, the lime, which is always present when calcium hypochlorite is used, clings persistently to the fibers.

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39. Use of Antichlor.—If an excess of bleach has been used, the stock is sometimes treated with *antichlor* (sodium thiosulphate $Na_2S_2O_3$), which destroys this excess bleach. Using antichlor is a very wasteful proceeding, since it causes a loss of the excess of bleach and of the thiosulphate, and it also leaves a residue of acid in the stock. This practice of using antichlor applies particularly to the treatment of stock in the beater room of the paper mill. The equation for the reaction is, according to Cross and Bevan,

$$2Ca(OCl)_2 + Na_2S_2O_3 + H_2O = 2CaSO_4 + 2NaCl + 2HCl.$$

Other reducing agents, as sodium sulphite Na_2SO_3 may also be used, and sulphite cooking liquor, which contains calcium bisulphite $Ca(HSO_3)_2$, has the same effect. The principle is: simply to supply a reducing agent that will be oxidized by the bleach before the latter has a chance to attack the cellulose. The reaction expressed by the following equation is typical of sulphites;

$$Ca(OCl)_2 + 2Na_2SO_3 = CaSO_4 + Na_2SO_4 + 2NaCl.$$

It is recommended that antichlors used in the pulp mill be added before washing the pulp. Testing with starch iodide will show when an excess of bleach is present, and control tests will show when to stop adding antichlor.

40. Use of Acid and Alum.—Acid is sometimes used to speed up the bleaching action. Acid promotes the decomposition of bleach, with the formation of hypochlorous acid and chlorine; the result is a very strong bleaching action, but very dangerous to cellulose. Alum, which by hydrolysis with water gives sulphuric acid, has the same effect. There should be no cause for the use of either acid or alum for this purpose. A small amount, however, may be added at the close of bleaching, to complete the action more quickly, and without damage to the cellulose. The equations of the reaction are, according to Cross and Bevan (see, also, Art. **10**),

$$Ca(OCl)_2 + 2HCl = CaCl_2 + 2HClO;$$
$$2HClO = 2HCl + 2O.$$

Thus a small amount of acid is used over and over as a catalyzer.

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OTHER METHODS OF BLEACHING

41. Use of Liquid Chlorine.—In recent years, a solution of chlorine gas, made from liquid chlorine and water, has come into use in the bleaching of rag stock. It cannot be used on sulphite or soda stock, because of the necessarily weak solution (due to the low solubility of chlorine) and the high price of the material. With regard to rags, it has certain advantages for mills that do not use bleach for other purposes; and these advantages are: (*a*) no handling of bleach drums and solutions; (*b*) no special equipment is necessary, in that liquid chlorine may be injected directly into the beater or washer where bleaching is done; (*c*) general cleanliness. The chief disadvantage is the danger of chlorine fumes, when poorly designed apparatus is used.

Liquid chlorine is shipped under high pressure in cylinders of 20 to 100 pounds capacity and also in drums; its cost is somewhat higher than its equivalent in bleaching powder.

42. Ozone; Hydrogen Peroxide; Potassium Permanganate.—These substances are all strong oxidizing agents, and have been proposed for bleaching. Ozone is a gas, and may be bubbled into a container of pulp; its molecule decomposes into nascent (atomic) oxygen, thus, $O_3 = 3O$. If no reducing agent is present, the reaction is represented by $2O_3 = 3O_2$, and oxygen gas escapes. A similar reaction occurs with hydrogen peroxide, a liquid; thus, $H_2O_2 = H_2O + O$. Both these substances are too expensive for commercial use.

Potassium permanganate $KMnO_4$ in neutral or alkaline solution furnishes atoms of oxygen; thus,

$$2KMnO_4 + H_2O = 2KOH + 2MnO + 5O$$

The manganous oxide MnO rapidly changes to the dioxide MnO_2, forming a dirty brown precipitate, which must be dissolved in sulphurous acid and washed out. The two operations are too costly to be practicable.

43. Use of Sulphur Dioxide.—Sulphur dioxide SO_2 has been tried in the bleaching of soda and sulphate pulps; it has little or no effect on soda pulp, but it does brighten up sulphate pulp to a considerable extent. However, its bleaching action is not permanent; the stock tends to revert to its former color, because SO_2 is a *reducing* agent, and compounds reduced by it may be re-oxidized by the air. It will be perceived that the chemical action of

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sulphur dioxide is just the opposite of that of bleaching powder, which is an *oxidizing* agent.

44. Bleaching of Sulphate Pulp.—Sulphate, or kraft, pulp is very difficult to bleach; it is usually made primarily for strength. This means raw cooking, to begin with, and any under-cooked pulp is hard to bleach. In order to bleach the usual sulphate pulp, large quantities of bleach and high temperatures are necessary. The result of this is, of course, very drastic action on the cellulose and a weakened product. The presence of a large quantity of shives in under-cooked pulp is one of the main sources of difficulty. Very little sulphate stock is bleached in America at the present time, but bleached sulphate is regularly quoted in European markets.

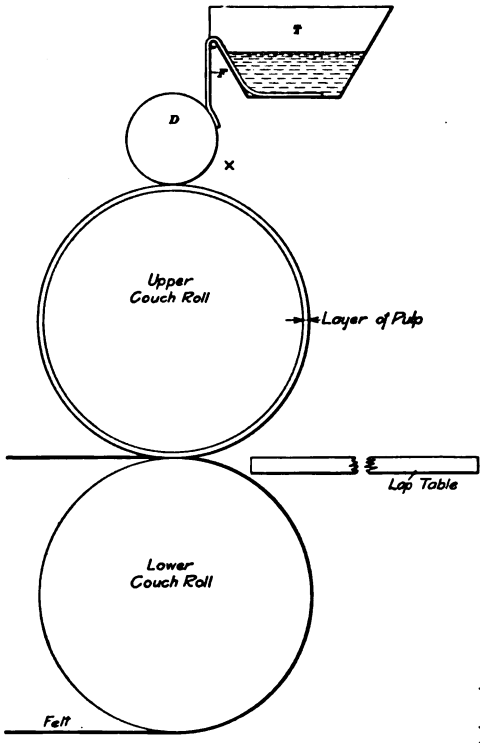

FIG. 8.

45. Bleaching of Ground Wood.—The bleaching of ground wood is accomplished by use of sodium bisulphite solution $NaHSO_3$. The action is similar to that of sulphur dioxide—a direct chemical reducing action on the wood, which alters its color.

In order to bleach ground wood, the solution of bleaching agent must be very strong; it cannot, therefore, be done in the ordinary stock vat, where much water is necessarily present. Fig. 8 shows one type of apparatus. A lead-lined trough *T*, one long edge rolled, is placed just over the distributing roll *D* of a wet machine. A strip of felt is laid over one edge of the trough, parallel to the roll *D*; one edge of the felt dips into the trough *T*, and the other hangs down 3 or 4 inches over the lip, touching

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the roll *D*. The trough *T* is filled with a 30% solution of sodium bisulphite, which is fed by the felt (acting as a wick) to the pulp sheet; about 2½ gallons of the solution must be used per ton of pulp. In place of the trough and wick, there may be placed, at × a 2-inch pipe, perforated every 2 inches with $\frac{1}{16}$-inch holes aimed at roll *D* and given a reciprocating movement of 2 inches for each revolution of the couch roll. The stock is allowed to stand for a few days, and gradually assumes a bleached appearance. Sometimes sulphuric acid (4 to 5 pounds per ton of pulp) is fed on the pulp separately; this hastens and improves the bleaching action, by reacting with the bisulphite and causing an evolution of sulphurous acid.

The bleaching action whitens the stock, and the presence of the chemicals also retards the destruction of stock by fungi, if long in storage. The bleaching is not permanent, and the stock gradually assumes a gray appearance. The process has the disadvantage of imparting to the stock the odor of sulphurous acid. To get a good product, selected spruce should be used, and it should be finely ground. This product is adapted to the manufacture of cheap book and magazine papers.

46. Bleaching of Rags.—Rags are very easily bleached in the washers, identical with the machine shown in Fig. 7, and discussed in detail in the Section on *Preparation of Rag and Other Fibers*, Vol. IV, in which they are cleaned and cut up into half stock. Here, again, the best results are had by heating the stock and using the maximum consistency possible. The highest consistency can be obtained by drawing off as much water through the washer cylinder as is possible, just before the bleach is added; the effect of doing this will be especially noted on oilies and colored rags, which are more difficult to bleach to a good white. For bleaching rags only, from 2% to 5% of bleaching powder on weight of stock is necessary. Care must be taken that excess bleach is removed, by thorough washing in the washers or drainers, or foaming on the machine will result. Of course, no excess bleach should be present, if the bleaching is properly done.

47. Bleaching of Old Paper.—Old papers are usually bleached in the same way as rags, that is, in washers. The bleach does not affect the printing inks, which should be previously removed from the paper by proper cooking, washing, and screening; but

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it does remove dirt, dyes, etc. From 1% to 2% of bleaching powder on the weight of stock is required.

48. Consumption of Bleach.—The consumption of bleach depends on many factors, among which are: the kind of wood used; the length and harshness of the cook; the care with which the pulp is washed; the efficiency of the bleaching process; etc. The following table shows the average bleach consumption in American mills in per cent of 35% bleach, based on the weight of air-dry pulp:

Sulphite pulp: 10–15% for spruce.
Soda pulp: 10–18% for poplar; 12–16% for mixed soft woods.
Rags: 1–2% for No. 1 cotton; 2–3% for No. 3 cotton; 3–5% for oilies and colored rags.
Waste papers: about 1% for old magazines.

It is evident that there is a considerable difference in the results. On sulphite, there is a difference of as much as 65% in the amount of bleach used by two different mills using the same kind of wood. With careful control and attention to operation, this high figure would, no doubt, be very much reduced.

49. Hazards.—The main hazards in bleaching result from the absorption by the body of chlorine gas and fumes from bleaching powder. In a chlorine plant or wherever bleach drums are handled, masks should be worn. Good ventilation is distinctly desirable.

QUESTIONS

(1) (*a*) What is the function (purpose) of the diaphragm in an electrolytic cell? (*b*) of the mercury?

(2) Describe fully and explain the operation of one type of bleaching apparatus.

(3) (*a*) What are the chief factors in bleaching pulp? (*b*) Explain the importance of each.

(4) Name certain substances that will bleach pulp, but are not so used, and explain why.

ANALYSIS OF BLEACH AND BLEACH LIQUOR

50. Methods of Testing.—Bleach is always tested in solution, and the test consists in determining the per cent of available chlorine or oxidizing power.

There are many different ways for determining the available chlorine, such as the use of arsenious oxide, sodium thiosulphate, and iodine solutions of various kinds. The method that is

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generally used by the manufacturers of bleach is the **Penot method,** which consists in titrating a solution of bleaching powder with a solution of sodium arsenite Na_3AsO_3. Potassium iodide-starch paper or solution is used as an indicator.

51. How to Make the Arsenite Solution.—For each liter to be made up, dissolve 4.95 grams of pure arsenious oxide As_2O_3 and 20 grams of anhydrous sodium carbonate in 250 c.c. of water. The carbonate, being alkaline, serves to keep the arsenious oxide in solution and to neutralize any acids formed in titrating. Only the As_2O_3 need be considered as taking part in the reactions. Dissolve in a beaker over a water bath. When the solution is complete, measure into a bottle, dilute to the necessary number of liters with distilled water, and standardize it against $\frac{N}{10}$ iodine solution that has just been standardized with pure sodium thiosulphate crystals. Arsenious oxide as purchased is, however, usually pure enough to enable a chemist to make up a standard solution without checking it up against the iodine; and 1 c.c. of the solution should be equivalent to .0127 g. of iodine or to .00355 g. of chlorine. If too strong, the solution can be diluted; if too weak, a factor must be used in making calculations or more arsenious oxide must be added, and the solution again standardized.

52. Standardizing the Sodium Arsenite.—(a) $\frac{N}{10}$ IODINE SOLUTION: Make up a $\frac{N}{10}$ iodine solution by dissolving 12.7 g. of iodine and 18 g. of potassium iodide KI (to increase the solubility of the iodine) in each liter of water used; 1 c.c. then contains .0127 g. of iodine, which is equivalent to .00355 g. of chlorine. The iodide does not take part as a reagent.

(b) STANDARDIZATION OF $\frac{N}{10}$ IODINE SOLUTION: Pour 300–400 c.c. of distilled water in a liter beaker and bring to boiling. Remove flame and dissolve in this water exactly 0.75 g. of barium thiosulphate $BaS_2O_3 \cdot H_2O$, with constant stirring. This requires about 5 minutes, on account of the slight solubility of the salt. Cool and titrate against the $\frac{N}{10}$ iodine solution, using a starch solution as an indicator. Then from the equation

$$2BaS_2O_3 \cdot H_2O + I_2 = BaI_2 + BaS_4O_6 + 2H_2O,$$

$$0.75 \text{ g. } BaS_2O_3 \cdot H_2O = 0.3558 \text{ g. } I_2 = 0.09941 \text{ g. } Cl_2$$

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Note: If barium thiosulphate is not at hand, a fifth normal solution of sodium thiosulphate, made by dissolving 49.6 g. of pure crystals ($Na_2S_2O_3 \cdot 5H_2O$) and making up to 1 liter with distilled water, may be used.

(c) STANDARDIZATION OF $\frac{N}{10}$ ARSENITE SOLUTION: To Standardize this against the $\frac{N}{10}$ iodine solution, use 30 c.c. of arsenite solution, and starch solution as an indicator. Always run the iodine solution into the starch solution; never reverse this. The iodine takes the place of the oxygen in the water and this combines with the As_2O_3 to form arsenic oxide As_2O_5; the iodine is an indirect oxidizing agent. There will be some sodium carbonate present to neutralize the hydriodic acid HI and the As_2O_5. Then,

$$As_2O_3 + 2H_2O + 2I_2 = As_2O_5 + 4HI$$

Adjust this solution so 1 c.c. will be equivalent to 0.00355 g. Cl_2.

53. Determination of Available Chlorine in Bleaching Powder. On an analytical balance, weigh out 7.1 grams of the sample, which must be carefully taken, using counterpoised watch glasses. Empty this sample into a clean porcelain mortar, washing off the watch glass with cold water from a wash bottle. Add a little more water, until the mortar is about one-third full, and work the bleach and the water together until it is well mixed and there are no lumps of bleach left. Transfer the solution, with the suspended bleach, into a standard liter flask; grind down the residual bleach, so that all small particles of bleach become impalpable; finally, wash all of this bleach into the flask, fill to the mark, and shake well.

Titrate 50 c.c. of the milky solution immediately after shaking with the $\frac{N}{10}$ arsenite solution. The titration gives directly the percentage of available chlorine in the sample. Use potassium iodide-starch paper[1] as an indicator.

[1] This paper may be made by soaking clean filter paper in a solution of 3 grams of soluble starch and 4 grams of potassium iodide in a liter of distilled water. The paper should be allowed to dry in an atmosphere free of chlorine or sulphurous acid. Then cut into strips of convenient size and store in an amber-colored, wide-mouth bottle until used. Some chemists prefer to put a few drops from a dropper bottle on a white surface(as paper) as needed. The end point is when a drop of the titrate solution fails to turn the starch blue.

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Example.—If 50 c.c. of bleaching powder solution (= *A*) require 40 c.c. of arsenite solution (= *B*), what was the percentage of chlorine in the sample?

Solution.—(*A*) $\frac{50}{1000} \times 7.1 = .355$ g. of powder in 50 c.c.

(*B*) $40 \times .00355 = .142$ g. of chlorine (equivalent of 40 c.c. of arsenite).

$\frac{.142}{.355} \times 100 = 40$ = per cent of chlorine in sample. *Ans.*

54. To Find the Weight of Bleaching Powder per Liter.—To determine bleaching powder in solution, use a 5 c.c. sample of the bleach solution, dilute to 25 c.c., and titrate directly with the arsenite solution, using potassium iodide-starch paper as the indicator. Each cubic centimeter of arsenite solution is equal to 0.00355 grams of chlorine. The number of cubic centimeters used gives the quantity of chlorine in the 5 c.c. sample; and this result multiplied by 200 gives the quantity of chlorine in 1 liter of bleach solution. This last result divided by 0.35 gives the grams of 35% bleaching powder in a liter of solution, which is the determination desired.

55. Alternative Method for Analysis of Bleach and Bleach Liquor.—Sodium thiosulphate and potassium or sodium iodide are employed, and the test is conducted as follows:

STANDARDIZATION OF SODIUM THIOSULPHATE SOLUTION, $Na_2S_2O_3$: Make up a standard solution of potassium permanganate ($\frac{1}{5}$th of the molecular weight of $KMnO_4$), approximately one-fifth normal; that is, dissolve in 1 liter of distilled water $\frac{1}{5} \times \frac{1}{5} \times 158 = 6.32$ g. of $KMnO_4$, the molecular weight of which is 158. Since each molecule of $KMnO_4$ will oxidize 5 hydrogen atoms, a liter of normal solution (see Vol. V) would contain $158 \div 5 = 31.6$ g., and the normality of the test solution is, therefore, the grams of permanganate used divided by 31.6. If the analyst should take 6.45 g. of permanganate, the solution would be $6.45 \div 31.6 = .204$ normal. Take 25 c.c. of this solution, add a few crystals of potassium or sodium iodide KI or NaI, and acidulate it with dilute hydrochloric acid HCl. Make up a solution of fifth normal sodium thiosulphate (49.6 g. of $Na_2S_2O_3 \cdot 5H_2O$ per liter) and titrate the permanganate solution with this until the solution becomes colorless. The number of cubic centimeters of permanganate solution multiplied by its normality and divided by the number of cubic centimeters of the thiosulphate gives the normality of the thiosulphate, and consequently the number of grams of chlorine equivalent to 1 c.c.

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Suppose, for example, that 27.36 c.c. of the thiosulphate solution and 25 c.c. of the permanganate solution were used, and the normality of the latter is .204; then the normality of the thiosulphate solution is $\frac{25}{27.36} \times .204 = .1865$. The normality (strength) of the thiosulphate must be less than the normality of the permanganate, i.e. each c.c. of thiosulphate is weaker, since more c.c. of the thiosulphate is required.

56. Determination of Available Chlorine.—Take a 5 c.c. sample of the bleach solution to be tested, whether electrolytic bleach or made from powder, and dilute to 100 c.c.; add 10 c.c. of potassium iodide (70 g. per liter), or its equivalent in sodium iodide (63.2 g. per liter), and 10 c.c. of acetic acid solution (50 c.c. of glacial acetic acid per liter). Titrate this with the standard sodium thiosulphate solution, with starch as an indicator, until the solution becomes colorless. (A few drops of starch solution are added toward the end of the reaction.)

In order to calculate the strength of the bleach solution analyzed, multiply the number of cubic centimeters of thiosulphate solution used by its normality and divide the product by the number of cubic centimeters of bleach solution used (in case of very strong solutions only 50 c.c. or even only 25 c.c. need be used, in order not to use more than one buretteful, 50 c.c., of thiosulphate); the quotient is the normality of the bleach solution. Multiply the quotient by the equivalent weight of chlorine, 35.5, and the product is the number of grams of available chlorine per liter. This last product divided by .35 gives the grams of 35% bleaching powder per liter.

Example.—Suppose it required 28 c.c. of sodium thiosulphate solution $\left(\frac{N}{5} = .2N\right)$ to reduce 100 c.c. of the bleach solution; how many grams of 35% available chlorine are in the sample of bleaching powder?

Solution.—Strength of bleach solution $= \frac{28 \times .2}{100} = .056$; $.056 \times \frac{35.5}{.35}$ = 5.68 g. of 35% bleaching powder per liter. *Ans.*

57. Testing the Liquor.—An approximation of the strength of fresh solutions of high test bleaching powder can be had by use of the hydrometer; but these should not be depended upon, since calcium chlorate, calcium chloride, lime, etc. are present in varying amounts and alter the density of the solution. However, this test may be used as a rough check in mill operation. Both the Baumé and Twaddell hydrometers are used, but the Baumé

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instrument is the more common. Tables for converting one reading into the other are given at the end of this volume.

The hydrometer reading changes with the temperature; so does bleach concentration, and in exactly the same proportion; hence, the quantity of bleach to be used can always be determined by the hydrometer reading (subject to conditions mentioned above) regardless of the temperature. However, for comparative results, all tests should be made at the same temperature.

58. Specific Gravity Table for Bleach Solutions.—The table given below, compiled by Lunge and Bachofen, shows the relationship between the specific gravity at 15°C. (59°F.) and the bleach concentration. The table refers to a solution of electrolytic bleach or high-grade bleaching powder. Commercial bleaching powder will show a higher hydrometer test, as compared with the actual bleach content, because of the presence of larger quantities of impurities, principally calcium chloride, formed by the decomposition of the powder. A correction of 8% should be made for the powder generally used. If poor powder is to be used, the correction must be much greater, and it can be determined only by a chemical analysis of the solution.

Careful tests of solutions made from powder should always be made, because bleach decomposes quite rapidly, even in air-tight drums; and large money losses, as well as poor pulp, may result unless care be taken.

CONCENTRATION AT VARIOUS SPECIFIC GRAVITIES

Sp. gr. at 15°C.	Grams per liter active chlorine	Sp. gr. at 15°C.	Grams per liter active chlorine
1.1000	61.50	1.0450	26.62
1.0950	58.00	1.0400	23.75
1.0900	55.18	1.0350	20.44
1.0850	52.27	1.0300	17.36
1.0800	49.96	1.0250	14.47
1.0750	45.70	1.0200	11.41
1.0700	42.31	1.0150	8.48
1.0650	39.10	1.0100	5.58
1.0600	35.81	1.0050	2.71
1.0550	32.68	1.0025	1.40
1.0500	29.60	1.0000	trace

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BLEACHING OF PULP

EXAMINATION QUESTIONS

(1) Write equations for (*a*) the reaction of chlorine with milk of lime and (*b*) of bleaching powder with water. Put the name of each substance under its molecular formula as it stands in the equations.

(2) What is meant by available chlorine?

(3) Explain the principle of the electrolytic cell.

(4) (*a*) What conditions favor the formation of chloride of lime? (*b*) Why is this formation to be avoided?

(5) If you were building a mill, (*a*) which method of bleaching would you choose and why? (*b*) How would you obtain your bleach?

(6) (*a*) Why should the man that cooks the pulp be interested in the way it bleaches? (*b*) What cooking conditions affect the bleaching operation?

(7) (*a*) What is antichlor? (*c*) why is it used? (*c*) why is its use objectionable?

(8) (*a*) How is groundwood bleached? (*b*) Why is the color not permanent?

(9) A sample of bleaching powder weighing 7.1 grams was dissolved in water, diluted to 1 liter, and 38 c.c. of standard sodium arsenite solution was oxidized by 50 c.c. of the bleach solution; (*a*) what was the percentage of chlorine in the bleach? (*b*) How many grams of chlorine per liter did the bleach contain?

Ans. { (*a*) 38%. (*b*) 2.7 g./1.

(10) What dangers are to be avoided when making bleach and handling bleaching powder?

(11) How is bleach tested?

(12) If 50 c.c. of bleach solution require 15.5 c.c. of $\frac{N}{5}$ sodium thiosulphate, what is the strength in grams per liter of 35% bleaching powder? Ans. 62 g./1.

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Table I

For Converting Degrees Twaddell to Degrees Baumé

Degrees Twaddell	Degrees Baumé	Degrees Twaddell	Degrees Baumé	Degrees Twaddell	Degrees Baumé	Degrees Twaddell	Degrees Baumé
1	0.72	26	16.68	51	29.46	76	39.93
2	1.44	27	17.25	52	29.92	77	40.31
3	2.14	28	17.81	53	30.37	78	40.68
4	2.84	29	18.36	54	30.83	79	41.06
5	3.54	30	18.91	55	31.28	80	41.43
6	4.22	31	19.45	56	31.72	81	41.79
7	4.90	32	20.00	57	32.16	82	42.16
8	5.58	33	20.54	58	32.60	83	42.53
9	6.24	34	21.07	59	33.03	84	42.89
10	6.90	35	21.60	60	33.46	85	43.25
11	7.56	36	22.12	61	33.89	86	43.60
12	8.20	37	22.64	62	34.31	87	43.96
13	8.85	38	23.15	63	34.73	88	44.31
14	9.49	39	23.66	64	35.15	89	44.66
15	10.12	40	24.17	65	35.57	90	45.00
16	10.74	41	24.67	66	35.98	91	45.35
17	11.36	42	25.17	67	36.39	92	45.69
18	11.97	43	25.66	68	36.79	93	46.03
19	12.58	44	26.15	69	37.19	94	46.36
20	13.18	45	26.63	70	37.59	95	46.70
21	13.78	46	27.11	71	37.99	96	47.03
22	14.37	47	27.59	72	38.38	97	47.36
23	14.96	48	28.06	73	38.77	98	47.68
24	15.54	49	28.53	74	39.16	99	48.01
25	16.11	50	29.00	75	39.55	100	48.33

Specific Gravity at x°Tw. = 1 + .005x. For 7°Tw., sp. gr. = 1 + .005 × 7 = 1.035.

Table II

For Converting Degrees Baumé to Degrees Twaddell

Degrees Baumé	Degrees Twaddell	Specific Gravity	Degrees Baumé	Degrees Twaddell	Degrees Gravity	Degrees Baumé	Degrees Twaddell	Specific Gravity
0	0	1	17	26.56	1.1328	34	61.26	1.3063
1	1.39	1.0069	18	28.34	1.1417	35	63.64	1.3182
2	2.80	1.0140	19	30.16	1.1508	36	66.06	1.3303
3	4.23	1.0211	20	32.00	1.1600	37	68.52	1.3426
4	5.67	1.0284	21	33.87	1.1694	38	71.03	1.3551
5	7.14	1.0357	22	35.77	1.1789	39	73.58	1.3679
6	8.63	1.0432	23	37.70	1.1885	40	76.19	1.3810
7	10.14	1.0507	24	39.67	1.1983	41	78.84	1.3942
8	11.68	1.0584	25	41.67	1.2083	42	81.55	1.4078
9	13.24	1.0662	26	43.70	1.2185	43	84.32	1.4216
10	14.81	1.0741	27	45.76	1.2288	44	87.13	1.4356
11	16.42	1.0821	28	47.86	1.2393	45	90.00	1.4500
12	18.05	1,0902	29	50.00	1.2500	46	92.93	1.4646
13	19.70	1.0985	30	52.17	1.2609	47	95.92	1.4796
14	21.37	1.1069	31	54.39	1.2719	48	98.97	1.4948
15	23.08	1.1154	32	56.64	1.2832	49	102.08	1.5104
16	24.81	1.1240	33	58.93	1.2946	50	105.26	1.5263

Specific Gravity at x°Be. = $\frac{145}{145 - x}$. For 15°Be., sp. gr. = $\frac{145}{145 - 15}$ = 1.1154.

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Table III

Properties of Saturated Steam

Vacuum in inches of mercury at 58.4°F. 30″ = 0 lb. pressure	Pressure (absolute) lb. per sq. in.	Temperature, Fahrenheit	Temperature, Centigrade	Latent heat of evaporation or condensation	Total heat of steam	Volume of 1 lb. of steam (cu. ft.)
29.8	0.10	34.42	1.34	1072.0	1074.4	3004.0
29.6	0.20	52.60	11.44	1061.8	1082.5	1554.0
29.4	0.30	63.86	17.70	1055.6	1087.5	1063.0
29.2	0.39	72.27	22.37	1051.0	1091.3	810.0
29.0	0.49	79.07	26.15	1047.2	1094.3	657.0
28.5	0.74	91.70	33.17	1040.3	1100.0	446.2
28.0	0.98	101.15	38.41	1035.0	1104.1	339.6
27.5	1.22	108.70	42.61	1030.8	1107.4	275.2
27.0	1.47	115.06	46.14	1027.2	1110.2	231.9
26.5	1.71	120.55	49.19	1024.1	1112.6	200.2
26.0	1.96	125.38	51.82	1021.4	1114.7	176.7
25.5	2.21	129.75	54.31	1018.9	1116.5	158.1
25.0	2.45	133.77	56.54	1016.6	1118.3	143.0
24.5	2.70	137.30	58.50	1014.7	1119.9	134.3
24.0	2.94	140.64	60.36	1012.8	1121.3	120.8
23.0	3.43	146.78	63.77	1009.3	1123.9	104.5
22.0	3.92	152.16	66.76	1006.2	1126.2	92.3
21.0	4.41	157.00	69.44	1003.4	1128.2	82.6
20.0	4.90	161.42	71.90	1000.8	1130.1	74.8
19.0	5.39	165.42	74.12	998.5	1131.8	68.5
18.0	5.88	169.14	76.19	996.4	1133.4	63.1
17.0	6.37	172.63	78.13	994.3	1134.8	58.6
16.0	6.86	175.93	79.98	992.3	1136.1	54.6
15.0	7.35	179.03	81.68	990.5	1137.4	51.2
14.0	7.84	181.92	83.29	988.8	1138.6	49.03
13.0	8.32	184.68	84.82	987.1	1139.7	45.55
12.0	8.82	187.31	86.28	985.5	1140.7	43.18
11.0	9.31	189.83	87.68	984.0	1141.7	41.05
10.0	9.80	192.23	89.02	982.5	1142.6	39.13
9.0	10.28	194.52	90.29	981.2	1143.6	37.40
8.0	10.78	196.73	91.52	979.8	1144.6	35.79
7.0	11.27	198.87	92.73	978.6	1145.4	34.33
6.0	11.76	200.94	93.86	977.4	1146.3	33.00
5.0	12.24	202.92	94.96	976.1	1147.0	31.76
4.0	12.74	204.85	96.03	974.8	1147.6	30.62
3.0	13.23	206.71	97.06	973.7	1148.4	29.55
2.0	13.72	208.52	98.07	972.6	1149.1	28.57
1.0	14.20	210.28	99.04	971.4	1149.7	27.66
0	14.69	212	100	970.4	1150.4	26.79

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Table IV

Properties of Saturated Steam

Pressure (gauge) lb. per sq. in.	Temperature, Fahrenheit	Temperature, Centigrade	Latent heat of evaporation or condensation	Total heat of steam	Volume of 1 lb. of steam (cu. ft.)	Pressure (absolute) lb. per sq. in.
0	212	100	970.4	1150.4	26.79	14.7
1	215.3	101.8	968.2	1151.6	25.23	15.7
2	218.5	103.6	966.2	1152.8	23.80	16.7
3	221.5	105.3	964.3	1153.9	22.53	17.7
4	224.4	106.9	962.4	1154.9	21.40	18.7
5	227.2	108.4	960.6	1155.9	20.38	19.7
6	229.8	109.8	958.8	1156.8	19.45	20.7
7	232.4	111.3	959.2	1157.2	18.61	21.7
8	234.8	112.6	955.5	1158.6	17.85	22.7
9	237.1	113.9	954.0	1159.4	17.14	23.7
10	239.4	115.2	952.5	1160.2	16.49	24.7
11	241.6	116.4	951.1	1161.0	15.89	25.7
12	243.7	117.6	949.6	1161.7	15.34	26.7
13	245.8	118.8	948.2	1162.4	14.82	27.7
14	247.8	119.9	946.8	1163.0	14.33	28.7
15	249.7	120.9	945.5	1163.7	13.88	29.7
16	251.6	122.0	944.2	1164.3	13.45	30.7
17	253.5	123.1	942.9	1164.9	13.05	31.7
18	255.3	124.1	941.6	1165.5	12.68	32.7
19	257.1	125.1	940.4	1166.1	12.33	33.7
20	258.8	126.0	939.3	1166.7	11.99	34.7
21	260.5	126.9	938.1	1167.2	11.67	35.7
22	262.1	127.8	936.9	1167.7	11.38	36.7
23	263.7	128.7	935.8	1168.2	11.09	37.7
24	265.3	129.6	934.8	1168.8	10.82	38.7
25	266.9	130.4	933.7	1169.3	10.57	39.7
26	268.3	131.3	932.5	1169.7	10.32	40.7
27	269.8	132.1	931.5	1170.2	10.09	41.7
28	271.3	132.9	930.5	1170.6	9.86	42.7
29	272.7	133.7	929.5	1171.1	9.65	43.7
30	274.1	134.5	928.5	1171.5	9.45	44.7
31	275.4	135.2	927.5	1171.9	9.26	45.7
32	276.8	135.9	926.6	1172.3	9.07	46.7
33	278.1	136.7	925.6	1172.7	8.89	47.7
34	279.4	137.4	924.7	1173.1	8.72	48.7
35	280.6	138.1	923.8	1173.5	8.56	49.7
36	281.9	138.8	922.9	1173.9	8.40	50.7
37	283.1	139.5	922.0	1174.8	8.25	51.7
38	284.3	140.2	921.1	1174.6	8.10	52.7
39	285.5	140.8	920.2	1174.9	7.95	53.7
40	286.7	141.5	919.4	1175.3	7.82	54.7

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TABLE IV.—*Continued*

PROPERTIES OF SATURATED STEAM

Pressure (gauge) lb. per sq. in.	Temperature, Fahrenheit	Temperature, Centigrade	Latent heat of evaporation or condensation	Total heat of steam	Volume of 1 lb. of of steam (cu. ft.)	Pressure (absolute) lb. per sq. in.
40	286.7	141.5	919.4	1175.3	7.82	54.7
42	289.0	142.8	917.6	1175.9	7.56	56.7
44	291.3	144.1	916.0	1176.6	7.32	58.7
46	293.5	145.3	914.3	1177.2	7.09	60.7
48	295.6	146.4	912.7	1177.8	6.88	62.7
50	297.7	147.6	911.2	1178.4	6.68	64.7
52	299.7	148.7	909.6	1178.9	6.50	66.7
54	301.7	149.8	908.2	1179.5	6.32	68.7
56	303.6	150.8	906.7	1180.0	6.14	70.7
58	305.5	151.9	905.3	1180.5	5.98	72.7
60	307.3	152.9	903.9	1181.0	5.83	74.7
62	309.1	153.9	902.5	1181.5	5.69	76.7
64	310.9	154.9	901.2	1182.0	5.56	78.7
66	312.6	155.8	899.8	1182.4	5.43	80.7
68	314.4	156.8	898.5	1182.9	5.30	82.7
70	316.0	157.7	897.2	1183.3	5.18	84.7
72	317.7	158.7	895.9	1183.7	5.07	86.7
74	319.3	159.6	894.6	1184.1	4.96	88.7
76	320.9	160.4	893.4	1184.5	4.86	90.7
78	322.4	161.3	892.2	1184.9	4.76	92.7
80	323.9	162.1	891.0	1185.3	4.67	94.7
82	325.4	162.9	889.8	1185.7	4.57	96.7
84	326.9	163.8	888.7	1186.1	4.48	98.7
86	328.4	164.6	887.5	1186.4	4.40	100.7
88	329.8	165.4	886.4	1186.8	4.32	102.7
90	331.2	166.2	885.2	1187.1	4.24	104.7
92	332.5	166.9	884.3	1187.5	4.17	106.7
94	333.9	167.7	883.2	1187.8	4.09	108.7
96	335.2	168.4	882.1	1188.1	4.02	110.7
98	336.6	169.2	881.1	1188.5	3.95	112.7
100	337.9	169.9	880.0	1188.8	3.89	114.7
102	339.2	170.6	879.0	1189.1	3.83	116.7
104	340.4	171.3	878.0	1189.4	3.76	118.7
106	341.7	172.1	876.9	1189.7	3.71	120.7
108	343.0	172.8	875.8	1189.9	3.65	122.7
110	344.2	173.4	874.9	1190.2	3.59	124.7
112	345.4	174.1	873.9	1190.5	3.54	126.7
114	346.6	174.7	873.0	1190.8	3.49	128.7
116	347.8	175.4	872.0	1191.1	3.43	130.7
118	348.9	176.1	871.0	1191.3	3.38	132.7
120	350.1	176.7	870.1	1191.6	3.34	134.7

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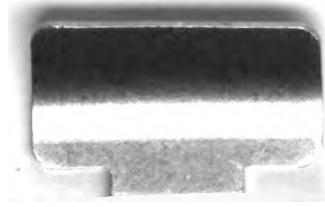

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